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Total-factor water efficiency of regions in China

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Abstract

Water is a limited and unevenly distributed resource in China, with the per capita amount of water resource there only about one-fourth of the world's average. However, water is an essential resource for people's lives and economic development. Over the past two decades China has seen the fruit of its rapid economic growth; nevertheless, a severe water shortage is behind this prosperous scenario and is becoming worse. Efficient water supply is certainly essential for the sustainable development of human beings. This paper analyzes water efficiency by incorporating water as an input as well as using conventional inputs such as labor employment and capital stock. An index of a water adjustment target ratio (WATR) is established from the production frontier constructed by data envelopment analysis (DEA) including water as an input. The water efficiency of regions is obtained from a total-factor framework with both residential and productive water use. A U-shape relation is discovered between the total-factor water efficiency and per capita real income among areas in China. The central area has the worst water efficiency ranking and the total adjustment amount of water used there is around three-fourths of China's total. More efficient production processes and advanced technologies need to be adopted in the central area to improve its water efficiency, especially for its productive use of water.

Keywords: Data envelopment analysis (DEA); Total-factor water efficiency; Water adjustment target ratio (WATR); Environment; China economy; Sustainable development

Introduction

Over the period 1979–2004, China's real GDP grew at an annual average rate of over 10.1% (National Bureau of Statistics of China, 2006), with the demand for resources as inputs for economic development increasing greatly. Water is one of those essential inputs to economic production, but it is in a severe shortage behind the prosperous economic boom in China. Many reports worry about whether the situation will improve and what will be the scenario in the future. As water resources are finite in China and also on earth, improving water efficiency to support sustainable development is a crucial task.

There is currently not much existing literature on the quantitative analyses of water efficiency. Related research (e.g., Mo et al., 2005; Huang et al., 2005) is concentrated mainly on agricultural productivity such as crop yields or the amount of food per unit of water consumed. The total-factor water efficiency of an economy or a region is left to be first developed by this research.

Water alone as an input cannot produce any outputs through production. It has to be accompanied by other inputs to produce real outputs. Therefore, a multiple-input model should be applied to evaluate the water efficiency in a region. Regional targets of water input, including residential and productive use, are found through data envelopment analysis (DEA). The inefficient portion of the water input results in redundant water consumption and shall be reduced. This redundant water use portion is generated mainly from inefficient production processes and out-of-date technologies. The two types of redundant water use portions are slack and radial adjustments of water input, and their summation is the total adjustment of water input. An index of a water adjustment target ratio (WATR) is constructed by dividing the target water

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input by the actual water input in a region or in an economy.

Water efficiency improvement relies on total factor productivity improvement (Boyd and Pang, 2000). The index WATR incorporates water as the input together with the conventional inputs in economic analysis being labor and capital stock. Multiple inputs therefore form an economic production function to produce the economic output (GDP[1]). An analysis of regional water efficiency in China shows an empirical result of a real case application of this newly developed index.

For the perspective of sustainable development, one needs to consider water policy (Gibbs, 2000) since water is an essential resource. Sustainable development should be introduced by covering areas on a local or regional level and then extending to the national level (Gibbs, 1998). This type of sub-national scale shall be emphasized as a key point. Our study concentrates specifically on the water efficiency status at the regional level in China, which was of less concern before, but is important now in order that further improvements can be planned and implemented accordingly. China is in a transition period starting from a high resource-consuming and low-efficiency economic development pattern (Yang, 2002; World Bank, 2001; Fleisher and Chen, 1997). It would be of particular importance to improve water efficiency for various regions in China in order to sustain its economic growth.

This paper is organized as follows: the following section overviews the situation of water resources in China and shows how water resources are scarce and unevenly distributed in China. "Research Methods" proposes the new index, WATR, of water efficiency based on a total-factor framework. "Empirical analysis result" constructs the regional performance of water efficiency in China based on this index. The administrative data and descriptive statistics are also given at the regional level in China. The results of water efficiency are shown for both residential use and productive use. The section "Concluding remarks" concludes this paper.

Water efficiency and sustainable development

China has uneven endowments of water resources among its regions, as some regions suffer from floods, while others suffer from droughts. In China 81% of its water resources are in the country's southern part, but the north, the political center, has the largest part of arable land of up to 64%, and is in a serious water crisis situation (Jin and Young, 2001). Water resources are characterized by richness in the south and shortages in the north, or richness in the east and shortages in the west (Zhong, 1999). On the other hand, the quantity of water resources greatly changes from year to year and also from season to season, making it difficult in developing and using water resources (Zhong, 1999).

[1]GDP represents gross domestic product.

The total amount of continental fresh water in China was estimated as 2413 billion cubic meters by 2004; however, per capita quantities of water in China were only 427 cubic meters. This amount is far away from the level of 1700 cubic meters which is defined by experts as starting to experience 'water stress' (World Resources Institute, 2004). The national supply was 554.5 billion cubic meters in 2004, in which the residential use portion was 46.1 billion cubic meters (8.3% of the total) and productive use was 500.2 billion cubic meters (90.2% of the total) (Ministry of Water Resources, 2004). As seen, productive use is the dominant portion of the total water use in China.

No matter whether China's policymakers push for less-efficient, capital-intensive water-transfer projects or opt for more efficient recycling and conservation in the north, China's unreliable water supplies could significantly affect its growth. Failure to solve water shortage problems could reduce China's annual GDP growth by 1.5% to 1.9% (Varis and Vakkilainen, 2001). Because of the high uneven endowed distribution of water resources among regions of China and also that the water resources are so much highly correlated to the productive use portion, it is worthy to investigate the efficiency of water use by regions especially on their productive use portion.

The regional efficiency of water use is analyzed on the basis of the three major areas: the east, the central, and the west area (Fig. 1). We would like to analyze the efficiency level of water use among these areas. The results can therefore be a reference of improvement on water supply and consumption.

Research methods

Regional water efficiency in China is evaluated on basis of the economic production frontier constructed by data envelopment analysis. Labor and capital stock are two major inputs in the production function. When measuring a nation's overall output, gross domestic product (GDP) is commonly used. For example, Färe et al. (1994) analyze the productivity growth of OECD countries, by considering labor and capital as inputs and the GDP as an output. Chang and Luh (2000) adopt similar inputs and the GDP output in order to analyze the productivity growth of 10 Asian economies. Hu (2006), Hu and Wang (2006), and Hu and Lee (forthcoming) also incorporate these inputs as well as natural resource inputs and the GDP output to analyze the total-factor energy efficiency of regions in China.

Because a significant correlation is found between water use and GDP, including two major portions from residential use and productive use; water use is therefore regarded as an input in conjunction with the inputs of labor and capital stock in a production function. These three input factors are regarded as the total inputs to produce economic output (GDP) in this study. DEA is launched to analyze efficiency and productivity based on this input–output production function. The target inputs and output for a region to be efficient can be computed by the DEA approach. The redundant and inefficient input amounts of inputs can therefore be calculated by the gap between their actual and target results, which are called slack and radial adjustment, respectively.

For an economy, water is certainly an essential resource for economic development as well as for people's living needs. Therefore, for an economic system or any region, it is essential that water usage should be efficient in order to reach the optimal sustainability of economic growth. A trade-off relationship actually exists between GDP output and water use in economic development. Increasing the GDP output of an economy means more water resources are required as it is highly, positively correlated to GDP output. Conversely, the water resource in a region has a natural limit making it impossible to supply unboundedly for GDP growth. The GDP growth and water consumption should hence be put together for balancing the goal of sustaining economic development as well as water supply. Thus, water efficiency is essential in being at its optimal use.

We first review the methodology of DEA in the following subsection. The target inputs and output are computed through DEA in order to reach the optimal efficiency and productivity of an economic system, whereby water use is considered in conjunction with other inputs. The slack and radial adjustment amounts of water input, including the portions of residential use and productive use, are obtained by the calculation of deviations between actual inputs and target inputs from DEA. The result is shown in the subsection "Slack and radial adjustments". The index water adjustment target ratio is therefore found in the subsection "Index of water adjustment target ratio". A U-shape relation is discovered between total water efficiency and per capita real income as disclosed in the subsection "Data sources".

Data envelopment analysis

DEA is known as a mathematical procedure using linear programming to assess the efficiencies of decision-making units (DMU) that refer to a set of firms (Coelli, 1996) and a set of regions in this study. All DMUs take an identical variety of inputs to produce an identical variety of outputs, but through distinct production processes and technologies decided and used in each DMU, the input and output levels and their production efficiency are eventually decided upon. A non-parametric piecewise frontier composed of DMUs, which own the optimal efficiency over the datasets, is constructed by DEA for comparative efficiency measurement. Those DMUs located at the efficiency frontier have their maximum outputs generated among all DMUs by taking the minimum level of inputs, which are efficient DMUs and own the best efficiency among all DMUs.

DEA specifies neither the production functional form nor weights on different inputs and outputs. It produces detailed information on the efficiency of the unit, not only relative to the efficiency frontier, but also to specific efficient units which can be identified as role models or comparators (Hu, 2006; Hu and Wang, 2006; Hu and Kao, 2007; Hu and Lee, forthcoming). Comprehensive reviews of the development of efficiency measurement can be found in Lovell (1993). There are K inputs and M outputs for each of these N DMUs.

The envelopment of the ith DMU can be derived from the following linear programming problem:

$$\begin{aligned} &\min_{\theta,\lambda} \quad \theta \\ &\text{such that} \quad -y_i + Y\lambda \geqslant 0, \\ &\qquad \theta x_i - X\lambda \geqslant 0, \\ &\qquad \lambda \geqslant 0, \end{aligned} \tag{1}$$

where θ is a scalar representing the overall technical efficiency (OTE) score; λ is an $N \times 1$ matrix of constants; y_i is an $M \times 1$ output vector of DMU i; x_i is an $K \times 1$ input vector of DMU i; Y is an $M \times N$ output matrix; and X is an $K \times N$ input matrix. This satisfies $0 \leqslant \theta \leqslant 1$ and a value of one indicates a point on the frontier, and hence a technically efficient DMU (Coelli et al., 1998). The above procedure constructs a piecewise linear approximation to the frontier by minimizing the quantities of the K inputs required to meet the output levels of the ith DMU. The weight λ serves to form a convex combination of observed inputs and outputs. It is an input-orientated measurement of efficiency.

Eq. (1) is known as the constant returns to scale (CRS) DEA model (Charnes et al., 1978). This model finds the OTE of each DMU. Later, the variable returns to scale (VRS) DEA model (Banker et al., 1984) further decomposes overall technical efficiency into pure technical efficiency (PTE) and scale efficiency (SE): OTE = PTE × SE. In order to pursue overall technical efficiency with water inputs, our study adopts the CRS DEA model. Furthermore, both output-oriented and input-oriented CRS DEA models generate exactly the same efficiency scores, target inputs, and target outputs. However, results of a VRS DEA model can be drastically changed by shifting from output orientation to input orientation.

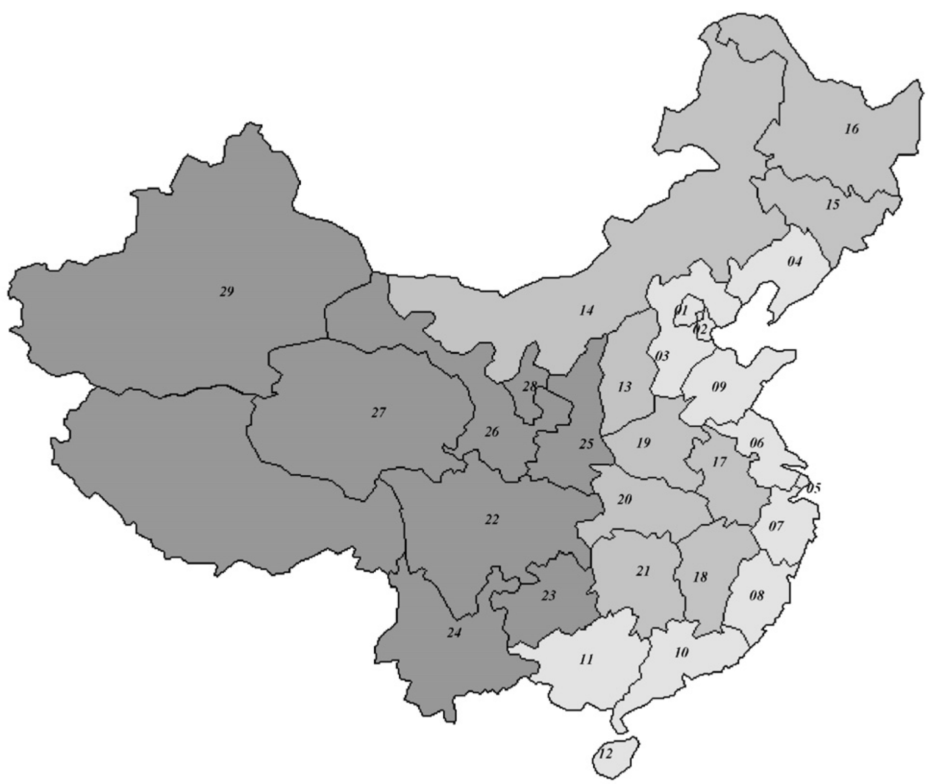
DEA provides a relative measurement instead of an absolute data comparison among DMUs. The efficiency frontier in DEA is constituted by those DMUs which own relatively the highest efficiency scores. This method therefore has an advantage natively that it is less sensitive to the absolute accuracy of data. Its efficiency measurement is actually done based on a relative data comparison and data rank. The existing gap from any DMU to the efficiency frontier shows how far the DMU should be further improved to reach the optimal efficiency level. The distance of the gap can also be computed through DEA. We use the software Deap 2.1, kindly provided by Coelli (1996), to solve the linear programming problems.

Slack and radial adjustments

DEA identifies the most efficient point on the frontier as a target for those inefficient DMUs to achieve through a sequence of linear programming computation (Coelli, 1996). For the ith DMU, the distance from an inefficient point, where it is located, to the projected point on the frontier by radial adjusting the level of inputs, $(1-\theta)x_i$, is called 'radial adjustment'. Moreover, the mostly seen piecewise-linear form of the non-parametric frontier causes the second stage to shift from the projected point to a point at the practical minimum level of the inputs on the frontier. The distance of shifting along with the frontier in between is called 'slack'.

How a point with a practical minimum level for inputs on the frontier can be identified in DEA is illustrated in Fig. 2 with a case of $M = 1$ and $K = 2$. The maximum level y output by the DMUs located on the frontier is normalized to unity and generated from the water input and other inputs which are also normalized by dividing y. Point B is the actual input set and point B′ is the projected point on the frontier for DMU B as the target in order to improve its efficiency accordingly by reducing the radial adjustment BB′. However, as aforementioned, the practical frontier is a piecewise linear format that requires the second-stage adjustment to determine a practical minimum point for inputs. In Fig. 2, point A′ is the projected point on the frontier for another DMU A as the target to reach by reducing the radial adjustment AA′. However, the input level at point A′ could be further reduced to the input level at point C while maintaining at the same time the same output level. The amount CA′ that shall further be adjusted for the input level at point A′ along with the frontier is called 'slack'.

The summation amount of slack (CA′) and radial adjustment (AA′) for inputs is called the amount of total adjustments (CA), meaning that it is the total amount for inputs which should be adjusted by a DMU so as to reach its optimal production efficiency. The adjustments require both a promotion of technology level and an improvement in the production process so that OTE is optimized. The amount of total adjustments therefore decreases and the output level is maximized so that the DMU operates at the frontier position of production efficiency. The practical minimum input level is called the target input level for a DMU.



East Area (12 Regions)						Central Area (9 Regions)				West Area (8 Regions)			
1	Beijing	6	Jiangsu	11	Guangxi	13	Shanxi	18	Jiangxi	22	Sichuan	27	Qinghai
2	Tianjin	7	Zhejiang	12	Hainan	14	Inner Mongolia	19	Hennan	23	Guizhou	28	Ningxia
3	Hebei	8	Fujian			15	Jilin	20	Hubei	24	Yunnan	29	Xinjiang
4	Liaoning	9	Shandong			16	Heilongjiang	21	Hunan	25	Shaanxi		
5	Shanghai	10	Guangdong			17	Anhui			26	Gansu		

Fig. 1. The administrative regions and three major areas in China.

The summation of slack and radial adjustment for input is the total adjustment amount, meaning the total amount needs to adjust so as to reach a 'target' input while keeping output unchanged. For the water input, this summation provides a 'water reduction target' (WRT) in a region and the formula is defined as follows:

$$\text{WRT} = \text{Radial adjustment of water input} + \text{Slack of water input.} \quad (2)$$

An inefficient economy unit can reduce WRT in water use without a reduction to its real economic growth. The production efficiency is therefore improved.

The CRS model of DEA suggests the slack and radical adjustment of the individual input for all observed units is efficient and the amount of target input can be calculated accordingly. The 'total adjustment amount' is then obtained from the gap between actual input amount and target input amount. The regional WRT of water input in China is computed according to this method.

Index of water adjustment target ratio

The WRT computed by DEA shows a target amount of water input to be reduced in an economy or a region in order to reach the optimal production efficiency at the frontier. However, it is hard to compare directly for the regional result since differences from the scale of economy and size of the region are not yet considered. A ratio format of WRT enables fair comparisons of regions by eliminating these differences, and therefore a simple index named the water adjustment target ratio (WATR) is constructed as a ratio format of WRT to measure the ratio of WRT to the amount of total water use in the region (Hu, 2006; Hu and Wang, 2006; Hu and Kao, 2007; Hu and Lee, forthcoming). The WATR index is constructed below:

$$\text{Water adjustment target ratio}(i,t) = \frac{\text{Water reduction target}(i,t)}{\text{Actual water input}(i,t)}, \quad (3)$$

which is in the ith region and the tth year.

The index WATR represents the target adjustment ratio of water use in each region. It reflects what ratio of water use is able to decrease without impacting the regional economic output level. The ratio is between zero and unity since WRT is equal to or larger than zero and is always smaller than the total water use. The null of this index represents an optimal and efficient production status in a region that has no water input amount needed to be saved since its water use condition is at the most efficient level, the minimum level, for economic output. Alternatively, the non-zero ratio of this index shows a certain ratio of amount of water use that needs to be reduced and adjusted in order that a minimum level of water use is adopted at economic production, which is at the production frontier.

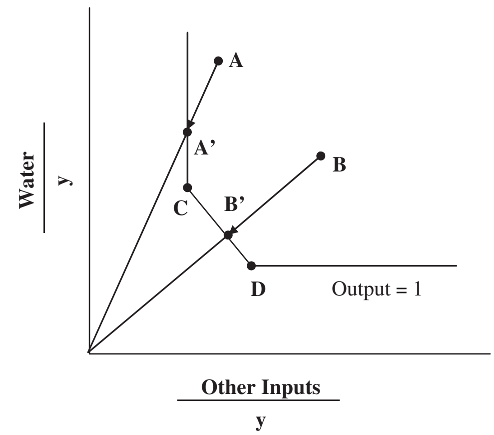


Fig. 2. Radial adjustment and slack identified in an input-oriented CRS DEA.

We will apply the WATR index to analyze water efficiency in regions of China in the following section.

Data sources

Regional data for inputs and the output are collected from distinct sources. Inputs including regional labor employment as well as water consumption are collected from the *China Statistical Yearbook* from 1997 to 2002. The water consumption is separated into two parts, residential use and productive use, according to data classification in the *China Statistical Yearbook*. The real capital stock as one of the input factors is constructed according to Li's method (Li, 2003) in 1997 prices.[2] The single output is regional GDP and is collected from the *China Statistical Yearbook* as well. All these factors are aggregated input and output proxies. Monetary inputs and outputs such as GDP and real capital stock are deflated to 1997 values. The thirty regions are categorized as three areas (shown in Fig. 1). The three areas are the east area (abbreviated as 'E'), the central area (abbreviated as 'C'), and the west area (abbreviated as 'W').

The east area is constituted by 12 regions that cover all coastal provinces from Liaoning in the north to Guangxi in the south. Shandong, Hebei, Jiangsu, Zhejiang, Fujian, Guandong, and Hainan are provinces in between. Beijing, Tianjin, and Shanghai are three municipalities that are also included in this area. The east area has experienced and still continues to have the most rapid economic growth in China, as its GDP output is around half of China's total. The east area has also attracted the most foreign investment, technology, as well as managerial know-how. The central area consists of nine regions that are all inland

[2]The capital stock data are not available in the *China Statistical Yearbook*. In this study, every regional capital stock in a specific year is calculated by the authors according to this formula: capital stock in the previous year + capital formation in the current year − capital depreciation in the current year. All the nominal values are deflated in 1995 prices before summations and deductions. We find the initial capital stock (capital stock data in 1995) from Li (2003).

provinces and are next to the coastal provinces: These regions are Heilongjiang, Jilin, Inner Mongolia, Hennan, Shanxi, Anhui, Hubei, Hunan, and Jiangxi. This area has the second largest population and developing economy just next to the east area. However foreign investment is less and technology lags do exist in this area. The west area covers more than half of the territory in China and includes the provinces of Gansu, Guizhou, Ningxia, Qinghai, Shaanxi, Tibet, Yunnan, Xinjiang, Sichuan, and a municipality: Chongqing. Compared to aforementioned two areas, this area has the lowest population density and is the least developed area in China.

From *China Statistical Yearbook*, we establish a dataset for 30 regions in China (27 provinces and 3 municipalities) during 1997 to 2002. Note that Chongqing became a municipality out of Sichuan just starting from 1997 and some of its data are split from Sichuan some years later. Therefore, we combine outputs and inputs of this municipality together with Sichuan in this study for easier comparison. Macroeconomic performance is evaluated in a region for its capability to maximize the single desirable output GDP and to minimize the three input factors. Water is especially important since it is an essential natural resource towards economic development.

Empirical analysis result

We conduct an empirical study to realize the status of water use efficiency for regions in China based on the defined production function including water as input and constructed by DEA. We shall based on this new index analyze the regional condition of water use in China and to strongly suggest this index is an effective indicator for the analysis of water efficiency.

Descriptive statistics

Table 1 shows the summary statistics of the aforementioned inputs and output including water as input that is ordered by region and area. The mean GDP output in the east area is 4.10 trillion RMB,[3] which is much higher than 1.90 trillion RMB of the central area and 0.95 trillion RMB of the west area during the sample's years. The variation of GDP output shows the same tendency and fits the economic growth scenarios among these areas, whereby the east area has about twice and four times the standard deviation in the central and west areas, respectively. For production inputs, the east area has the highest capital stock. The mean of capital stock of the east area is also around twice and four times higher than that of the other two areas, which are 36.1, 12.8, and 6.88 trillion RMB, respectively. The input of labor employment is not too much different between the east area and the central area. The west area gets the least labor employment since this area has also the lowest population in China.

The situation of water use appears to have the similar scenario of GDP output and capital stock input. The east area, from its economic growth result, consumes the largest water amount in China for both residential use and productive use. As Table 1 shows, the east area consumes 10.4 billion tons (Bt) of water for residential use and 11.6 Bt of water for productive use on average during the sample's period. These amounts are already over 50% of China's total. The central area is the second largest consumption area of water, consuming 5.6 Bt of water for residential use and 9.0 Bt of water for productive use on average. The amount of water this area consumes, both at residential use and productive use, occupy more than 30% of China's total. On the other hand, it is worth to note only this area, the central area, consumes water more for productive use than for residential use. With the lowest population in the west area, this area consumes the least residential use of water amount among the three areas. The productive use amount of water consumption in this area is also the lowest among the three areas.

A correlation matrix is shown in Table 2, whereby a high correlation exists between these three inputs and GDP output. All inputs have positive correlation coefficients with the output, which explain that all inputs satisfy the isotonicity property with the output. The correlation coefficient is 0.852 between residential use water input and GDP output and 0.807 between productive use water input and GDP output, in which all show statistical significance. The high correlation reveals that proportional relationships do exist between GDP output and both residential use and productive use of water consumption. It does explain that water consumption performs a significant input to generate economic output together with the other inputs in the production function. Water efficiency shall be analyzed on the basis of this production function with multiple inputs in a framework of total factor productivity. As water is an essential and finite resource for economic development and all life on earth, the efficiency of water use should have the highest concern.

WATR of residential use

The regional WATR of residential use water consumption in China is computed and constructed by DEA through the aforementioned method. The result is shown in Table 3. An average 4.03% WATR of total residential water amount is found in China during the research period. This ratio can be further reduced in order to improve its total-factor water productivity by regions onto a frontier position.

The east area and west area have low WATR on their residential water use amount. Regions in the east area have an average rate of 1.6% in WATR during the sample years. Guangxi (11) is the only region in this area having non-zero WATR. This region has an average rate of 20.3% in its

[3]The RMB is an abbreviation for Ren-Min-Bi, meaning the 'people's currency' in Chinese. The RMB is the official currency of the People's Republic of China.

Table 1
Summary statistics of inputs and the output by region (1997–2002)

ID	Region		Inputs								Output	
			Labor employment (10,000 persons)		Capital stock (100 million RMB)		Residential use water (1 million tons)		Productive use water (1 million tons)		Gross domestic products (100 million RMB)	
			Mean	STDev.	Mean	STDev.	Mean	STDev.	Mean	STDev.	Mean	STDev.
1	Beijing	E	659.58	69.84	24,988.62	3201.89	663.14	151.11	332.80	101.36	1759.75	241.89
2	Tianjin	E	426.67	33.05	14,254.40	1745.93	261.81	32.02	293.65	27.91	1161.07	147.46
3	Hebei	E	3400.70	23.81	18,742.61	4484.50	692.34	125.97	976.01	198.33	3604.71	428.92
4	Liaoning	E	1860.98	100.39	71,317.28	4658.69	979.77	197.44	1646.47	148.41	3252.34	352.79
5	Shanghai	E	704.30	42.06	43,254.53	5186.85	1,096.10	235.76	1161.69	133.76	3159.97	351.02
6	Jiangsu	E	3601.02	82.72	52,552.91	8093.94	1379.83	204.98	1789.32	150.58	6128.55	776.99
7	Zhejiang	E	2719.92	70.52	31,382.28	5447.00	774.61	152.75	916.63	50.92	4325.57	608.96
8	Fujian	E	1652.58	37.65	14,740.25	3442.23	505.22	64.36	619.77	76.18	2766.25	320.79
9	Shandong	E	4691.35	35.76	40,857.52	8441.60	878.99	140.35	1302.66	106.79	6093.32	770.49
10	Guangdong	E	3845.47	101.36	37,630.67	7491.29	2432.26	461.27	1879.02	109.00	6784.71	823.17
11	Guangxi	E	2508.18	46.54	7996.16	1367.61	570.47	57.46	659.13	51.38	1560.91	284.26
12	Hainan	E	832.17	1225.52	3797.87	480.51	142.20	24.73	45.12	13.16	365.48	44.37
13	Shanxi	C	1432.63	26.00	11,375.91	1591.93	337.98	25.27	455.26	56.60	1220.60	195.18
14	Inner Mongolia	C	1019.02	15.81	8463.75	1208.72	204.77	33.26	352.68	27.21	1004.19	127.60
15	Jilin	C	1109.48	73.11	10,045.65	1513.60	370.42	42.59	960.20	17.68	1314.32	163.90
16	Heilongjiang	C	1659.00	37.28	14,825.56	2234.12	560.47	49.54	853.86	53.27	2338.68	310.11
17	Anhui	C	3351.93	41.71	14,701.02	2354.58	606.29	68.49	1228.82	51.98	2250.54	323.71
18	Jiangxi	C	1905.63	189.28	10,968.99	1710.33	480.60	45.11	820.64	231.34	1494.07	211.75
19	Hennan	C	5305.32	264.27	24,394.35	4425.40	739.68	80.68	1029.00	144.87	3657.20	449.16
20	Hubei	C	2554.20	98.05	20,218.53	3793.83	1350.67	124.07	1643.90	419.78	3049.24	363.31
21	Hunan	C	3492.48	53.04	12,959.73	2639.65	923.10	63.73	1612.82	96.48	2624.25	326.09
22	Sichuan	W	6128.15	102.25	19,157.13	4549.15	1085.91	130.31	1198.51	291.11	4102.72	551.32
23	Guizhou	W	2007.47	66.07	5425.26	967.06	191.54	34.94	194.26	50.81	709.75	85.33
24	Yunnan	W	2291.70	35.02	8928.69	1610.76	229.20	54.11	179.09	39.70	1420.93	189.92
25	Tibet	W	300.62	432.97	1692.84	110.58	32.16	6.76	10.92	2.43	82.98	14.04
26	Shaanxi	W	1810.88	33.30	12,852.80	1701.00	353.14	68.80	270.42	42.33	1187.44	150.94
27	Gansu	W	1195.22	29.54	7,176.94	939.35	192.50	14.49	508.66	80.62	709.37	83.12
28	Qinghai	W	238.87	5.70	2294.02	331.70	62.75	9.14	68.45	9.03	190.31	25.76
29	Ningxia	W	270.77	9.11	2496.11	338.90	77.20	13.43	131.46	13.47	191.83	24.13
30	Xinjiang	W	683.00	11.99	8799.90	1352.47	230.33	20.78	210.66	22.42	948.34	110.00
	Sum		63,659.28	3393.76	558,262.28	87,343.17	18,405.42	2,733.74	23,351.85	2,818.91	69,459.08	8856.49
	East		26,902.92	1869.24	361,485.11	54,042.03	10,376.74	1,848.20	11,622.25	1,167.79	40,962.32	5151.11
	Central		21,829.70	798.57	127,953.48	21,400.17	5573.97	532.75	8957.18	1,099.20	18,953.10	2470.81
	West		14,926.67	725.96	68,823.69	11,900.97	2454.72	352.78	2772.42	551.92	9543.67	1234.57

Notes:
(1) All monetary values are in 1997 prices.
(2) Source: *China Statistical Yearbook*, 1997–2002.
(3) Data for administration region Chongqing are regarded as part of Sichuan.

Table 2
The correlation matrix for inputs and output (1997–2002)

	GDP	Capital	Labor	Water for residential use	Water for productive use
GDP	1.000				
Capital	0.728	1.000			
Labor	0.726	0.358	1.000		
Water for residential use	0.852	0.665	0.573	1.000	
Water for productive use	0.807	0.675	0.637	0.830	1.000

residential use water amount, which represents 116.54 million tons of water. This amount is analyzed and should be possibly reduced from this region without any impacts to its current GDP output level. The WRT amount can be found from Table 4 in a yearly format. Beijing (01) is another region to be noted with a higher average rate of WATR, which is 4.8% during the research period. As shown in Table 3, WRT began to exist in this region only by 2002, with 236.22 million tons of water in terms of amount. This amount is 22.76% of the area's total and is a significant portion in this area. Some other regions in this area are non-zero, but have a low WATR in certain years. For example, Hebei (03) has a 10.54% WATR in 1999 and

Table 3
WATR of residential use by region (1997–2002)

ID	Region		1997	1998	1999	2000	2001	2002	Average
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	28.80	4.80
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	0.00	0.00	10.54	0.00	0.00	0.00	1.76
4	Liaoning	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Zhejiang	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Guangxi	E	28.59	22.77	19.19	12.62	17.80	20.84	20.30
12	Hainan	E	0.00	0.00	0.00	6.38	0.00	0.00	1.06
13	Shanxi	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Inner Mongolia	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Jilin	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Heilongjiang	C	0.00	0.00	1.64	8.19	0.00	0.00	1.64
17	Anhui	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Jiangxi	C	0.00	4.63	0.53	0.00	0.00	0.00	0.86
19	Hennan	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Hubei	C	37.36	37.39	32.44	32.79	11.65	7.24	26.48
21	Hunan	C	29.51	27.96	22.89	0.00	25.78	15.54	20.28
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	4.33	0.00	0.00	0.74	0.00	11.32	2.73
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	9.13	0.00	0.00	0.00	1.52
27	Gansu	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Qinghai	W	11.93	0.00	0.00	0.00	0.00	0.00	1.99
29	Ningxia	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Xinjiang	W	0.00	0.00	1.06	0.00	0.68	0.00	0.29
	Total		5.34	5.09	4.72	2.79	3.06	3.17	4.03
	East		1.66	1.30	1.93	0.67	1.09	3.06	1.62
	Central		14.06	14.19	11.54	8.38	7.46	4.34	9.99
	West		0.73	0.00	1.48	0.05	0.07	1.03	0.56

Notes:
(1) The unit is percentage of the target to actual residential water use of the region or the area.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for administration region Chongqing are regarded as part of Sichuan in this paper.

Hainan (12) has a 6.38% WATR in 2000. These results are suspected as special cases for having non-zero WATR in these areas in certain years during the period.

Regions in the west area have an average rate of 0.56% WATR which needs to be improved. Guizhou (23) has non-zero WATR for four years in the period: 4.33% in 1997, 0.74% in 2000, 11.32% in 2002, and 2.73% during the period. The result shows quite a dynamic water utilization condition in this region and it may result from a complex geographical limitation of mountainous terrain, limestone karsts, spiky hills, and diverse river basins (World Bank, 1997), making water resource management difficult to construct in order to balance water use in this region. Other regions in this area always have non-zero WATR during the research period. Shaanxi (26) has 9.13% in 1999. Qinghai (28) has 11.93% in 1997, but finally goes to zero in the period, which demonstrates a significant improvement of residential water use efficiency after 1997. Xinjiang (30) has low non-zero WATRs, which are 1.06% in 1999 and 0.68% in 2001. Generally speaking, a low level of WATR represents high total-factor water efficiency in this area.

The central area gets high WATR for residential use water according to our analysis result shown in Table 4. The high redundant portion of residential use water shall be considered as decreasing. The area has an average rate of 9.99% WATR during the research period. This ratio is much higher than that of the other two areas. It reflects that the central area is a major source of inefficient residential water use in China. Two regions are the main reasons to generate these inefficient water use amounts in this area. Hubei (20) owns an average WATR of 26.48% on 354.11 million tons of residential water in terms of amount to be considered to save in total. Hunan (21) has an average WATR of 20.28%, representing 183.86 million tons of residential water to be considered for saving. There are two other regions that also have non-zero WATR in certain years, but are small compared to that of Hubei and Hunan. Heilongjiang (16) has 1.64% WATR in 1999; the ratio quickly goes up to 8.19% in 2000 and then returns to zero in a later research period. Jiangxi's (18) WATR is 4.63% in 1998 and then decreases to 0.53% in 1999. It has zero WATR after 1999 which is regarded as an improvement of efficiency.

As a result we have obtained from the calculation of WATR the following: region Guangxi (11) in the east area, regions Hubei (20) and Hunan (21) in the central area, and region Guizhou (23) in the west area are the four main sources generating reducible amounts of residential water use amount in China during the research period. These regions all have one similarity in that they are all located right next to rivers or lakes that could make residents in these regions are used to consuming more water for living use than other regions. In Guangxi (11) in the east area, there are four rivers: Yu River, Qian River, Gui River, and Lijiang River (World Bank, 2001) flowing through it, which are all tributaries to Xi River which is also the tributary to the largest river in southern China, the Pearl River. It is estimated that the surface water flowing in the region amounts to 188 billion cubic meters, accounting for 6.9% of the nation's total water and ranking fourth among all regions.

In the central area, regions Hubei (20) and Hunan (21) have a similar condition. In Hubei, the Yangtze River enters from the west via the Three Gorges and the Han River enters from the northwest. These two rivers meet at Wuhan, the provincial capital. Thousands of lakes dot the landscape, giving Hubei the name: "Province of Lakes". The two largest of these lakes are Lake Liangzi and Lake Honghu. The Danjiangkou Reservoir lies on the border between Hubei and Hunan. In Hunan, the Xiangjiang, the Zijiang, the Yuanjiang, and the Lishui Rivers converge on the Yangtze River at Lake Dongting in the north of the

Table 4
WRT amounts of residential use for regions and areas in China (1997–2002)

ID	Region		1997	1998	1999	2000	2001	2002	Average	Regional ratio
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	236.22	39.37	22.76
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	0.00	0.00	94.96	0.00	0.00	0.00	15.83	9.15
4	Liaoning	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Zhejiang	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Guangxi	E	164.77	132.59	112.54	70.51	83.81	135.01	116.54	67.36
12	Hainan	E	0.00	0.00	0.00	7.61	0.00	0.00	1.27	0.73
13	Shanxi	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Inner Mongolia	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Jilin	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	Heilongjiang	C	0.00	0.00	9.18	46.68	0.00	0.00	9.31	1.69
17	Anhui	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
18	Jiangxi	C	0.00	22.48	2.57	0.00	0.00	0.00	4.18	0.76
19	Hennan	C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Hubei	C	495.53	512.15	433.19	432.09	138.18	113.54	354.11	64.21
21	Hunan	C	262.25	253.95	204.92	0.00	220.98	161.09	183.86	33.34
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	8.21	0.00	0.00	1.37	0.00	29.38	6.49	44.84
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	35.58	0.00	0.00	0.00	5.93	40.94
27	Gansu	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
28	Qinghai	W	8.43	0.00	0.00	0.00	0.00	0.00	1.40	9.70
29	Ningxia	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Xinjiang	W	0.00	0.00	2.50	0.00	1.43	0.00	0.65	4.52
	Total								738.95	Arena ratio
	East								173.00	23.41
	Central								551.46	74.63
	West								14.48	1.96

Notes:
(1) The unit is million tons of water.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for administration region Chongqing are regarded as part of Sichuan in this paper.

region. The central and northern parts are somewhat low and have a U-shaped basin: open in the north and with Lake Dongting as its center. Most of Hunan Province lies in the basins of four major tributaries of the Yangtze River. Lake Dongting is the largest lake in the province and the second largest freshwater lake of China. Due to the reclamation of land for agriculture, Lake Dongting has been subdivided into many smaller lakes, though there is now a trend to reverse some of the reclamation, which has damaged wetland habitats surrounding the lake (World Bank, 2001).

In the west area, region Guizhou (23) has the landforms with a widely dispersed Karst topography; thus, it is famous for having created picturesque scenery with grandeur. Therefore, the region is rich in water resources with such a special geography. Wujiang River, a southern tributary of the Yangtze River, has the largest drainage area within the boundaries of Guizhou Province. Wujiang River runs through 23 counties, cities, and prefectures (special zones) of Guizhou, with a total length of 874 km in Guizhou boundaries (including 72 km of boundary river between Guizhou and Sichuan) and a total drainage area of 66,800 km^2. On the other hand, Huangguoshu Waterfall is located in this region which is the largest waterfall in China. The geographical differences explain how these four regions in the central area own a higher portion of WATR in residential water use. The WATR ratios of residential use water are relatively low and almost nothing in the other regions of this area.

The result of WATR in the residential use portion in China represents that residential water use is a necessity to life such that it is not over-consumed in most regions. There are only several regions used to consuming more water for the purpose of living, as they are richer in water resources than others. The residential use water amount is proportional to geographical condition by region, which determines the condition of population and the style of living at each region accordingly.

WATR of productive use

From the data collection of separate portions of water consumption in residential use and productive use, we are capable of reviewing water use efficiency at the productive use part. Water is well known as an essential natural resource to most economic production, which significantly influences economic growth directly. The analysis of efficiency in productive water use is hence rather important. The WATR of productive use water induces that the ratio of productive use water can be further saved and reduced. It is to be emphasized that the same economic output can still be retained at the same time when this redundant portion is removed. Since water is an essential resource in this planet, we need to improve productive water use to be efficient in order to maintain economic development.

The result of the productive use WATR of regions in China is shown in Table 5. The index of water adjustment target ratio is established from production frontier constructed by data envelopment analysis including water as an input. Also, the production frontier is constructed by regional data in China. Therefore, these zeros simply say that half of the regions in China are using water for productive use efficiently with respect to the Chinese frontier. They may not still be efficient with respect to the world frontier. The non-zero ratios show that half of the regions are not using water for productive use efficiently even with respect to the Chinese frontier. Therefore, these inefficient regions should apply the available technologies and methods that already exist in China to save water and hence improve their water use efficiency for productive use.

It can be observed that strikingly high WATR does exist in the productive use water of China's total. The average rate of 14.32% shows there to be a reducible amount of productive use water. The ratio is much higher than average rate of 4.03% WATR to be reduced in the residential use water portion. In terms of quantity, the saved target of productive use is 3317.62 million tons of water, which is almost four times larger than 738.95 million tons WRT of total residential use water. All three areas have higher WATR average rates in productive use water than that in residential use water, as can be seen in Table 5. The east area has an average 6.76% of WATR in productive use water, which is about five times larger than its WATR of residential use part: 1.62%. Same as that of the central area, its average WATR is 26.74% in productive use water, which is much more than the average 9.99% WATR in its residential use water. The west area also has a high WATR for productive use versus that for residential use, which are on average 5.65% and 0.56%, respectively.

In the east area, Liaoning (04) and Guangxi (11) are the two major regions generating WRT for productive use water. Liaoning (04) has on average 23.93% WATR to be adjusted, which refers to 392.37 million tons of water. Guangxi (11) has 23.66% WATR on average of productive use water, which refers to 150.91 million tons of water. The over-consumed water amount is related to abundant water resources in the region as aforementioned. Jiangsu (06) and Hebei (03) are another two regions in this area generating the main sources of WATR. Jiangsu (06) has on average 8.05% WATR of productive use water to be adjusted, which refers to 143.63 millions tons of water. Hebei (03) has on average 6.31% WATR of productive use water, which is 76.51 million tons of water. Zhejiang (07) is the other region which has non-zero WATR that is on average 1.58% WATR of productive use water. All these regions are deployed with major industries and are the main driving areas for economic growth in China. Their WATR

Table 5
WATR of productive use by region (1997–2002)

ID	Region		1997	1998	1999	2000	2001	2002	Average
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	18.40	19.48	0.00	0.00	0.00	0.00	6.31
4	Liaoning	E	12.08	20.55	27.57	23.03	38.45	21.92	23.93
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	9.18	8.86	3.33	9.02	17.91	8.05
7	Zhejiang	E	0.00	0.00	0.00	0.00	3.28	6.19	1.58
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Guangxi	E	12.22	13.40	16.20	16.39	42.39	41.34	23.66
12	Hainan	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Shanxi	C	0.00	2.99	2.03	3.45	0.00	4.92	2.23
14	Inner Mongolia	C	7.16	9.07	10.87	9.16	16.84	22.18	12.55
15	Jilin	C	28.12	33.42	36.17	38.68	48.27	50.47	39.19
16	Heilongjiang	C	15.36	13.91	17.06	21.36	25.53	29.53	20.46
17	Anhui	C	21.74	24.29	30.15	31.27	39.39	39.28	31.02
18	Jiangxi	C	3.46	10.17	12.04	1.65	46.74	35.69	18.29
19	Hennan	C	8.46	10.37	0.00	2.85	0.00	0.00	3.61
20	Hubei	C	36.64	40.20	37.35	27.19	21.14	0.00	27.09
21	Hunan	C	40.94	45.13	49.36	0.00	62.82	59.78	43.00
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Gansu	W	27.42	27.11	28.88	27.21	26.54	28.55	27.62
28	Qinghai	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Ningxia	W	9.52	9.76	8.65	6.65	17.72	15.61	11.32
30	Xinjiang	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total		11.71	14.39	14.47	9.36	19.50	16.47	14.32
	East		4.21	7.07	6.33	4.83	9.80	8.34	6.76
	Central		23.46	26.87	27.56	16.54	35.05	30.96	26.74
	West		5.50	4.97	5.48	5.25	6.69	6.00	5.65

Notes:
(1) The unit is percentage of target to actual productive water use of the region or the area.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for administration region Chongqing are regarded as part of Sichuan in this paper.

data have been relatively low compared to other regions of China, but they still should reduce these amounts in the future.

The central area is the worst area in efficiency for consuming productive use water. As seen in Tables 5 and 6, none of the regions in this area are at optimal efficiency of utilizing productive use water. Hunan (21), Jilin (15), Anhui (17), Hubei (20), Heilongjiang (16), Inner Mongolia (14), and Jiangxi (18) have higher WATR on average: respectively, 43.0%, 39.19%, 31.02%, 27.09%, 20.46%, 18.29%, and 12.55% of their productive use water amount. These ratios refer, respectively, to 687.12, 375.34, 378.87, 495.86, 172.13, 179.17, and 43.34 million tons of water that are capable of being reduced without suffering from economic performance. Hunan (21) and Hubei (20) are the two regions owning abundant water resources as aforementioned, and so they could also consume more water than other regions for productive use. Anhui (17) and Jilin (15) have a solid industrial base. Jilin (15) has six dominant industries, which are engineering industry, petrochemical industry, pharmaceutical industry food industry, metallurgical, and forestry industry. Jilin (15) also leads the country in its production of automobiles, railway cares, tractors, ferroalloy, carbonic products, timber, sugar, crude oil, vegetable oil, and non-mineral products. Economic development in Anhui (17) lags its neighborhood provinces, however, it is rich in natural resources of iron, coal, and copper so that it also has become a manufacture base. Heilongjiang (16) is another province which is the traditional base of industry for China. Industry there focuses upon coal, petroleum, lumber, machinery, and food. There are also certain levels of production deployed in Jiangxi (18) and Inner Mongolia (14). All manufacturing activities in these regions may involve out-dated production technology and have a massive scale of production, and therefore

Table 6
WRT amounts of productive use for regions and areas in China (1997–2002)

ID	Region		1997	1998	1999	2000	2001	2002	Average	Regional ratio
1	Beijing	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	Tianjin	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	Hebei	E	229.87	229.21	0.00	0.00	0.00	0.00	76.51	9.82
4	Liaoning	E	210.91	367.93	467.39	376.90	630.99	300.10	392.37	50.38
5	Shanghai	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	Jiangsu	E	0.00	182.65	153.78	57.52	140.80	327.03	143.63	18.44
7	Zhejiang	E	0.00	0.00	0.00	0.00	30.98	61.16	15.36	1.97
8	Fujian	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	Shandong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Guangdong	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Guangxi	E	88.94	91.21	109.17	108.08	271.14	236.91	150.91	19.38
12	Hainan	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Shanxi	C	0.00	15.17	9.84	16.66	0.00	19.11	10.13	0.42
14	Inner Mongolia	C	27.84	33.78	39.90	30.63	53.72	74.18	43.34	1.82
15	Jilin	C	275.28	323.88	351.28	368.02	448.71	484.88	375.34	15.74
16	Heilongjiang	C	141.94	122.75	148.91	182.30	209.30	227.57	172.13	7.22
17	Anhui	C	282.84	300.62	368.35	385.93	488.09	447.36	378.87	15.89
18	Jiangxi	C	25.01	74.80	86.10	11.40	602.82	274.90	179.17	7.52
19	Hennan	C	106.84	116.84	0.00	28.54	0.00	0.00	42.04	1.76
20	Hubei	C	749.18	828.52	696.60	417.86	283.02	0.00	495.86	20.80
21	Hunan	C	690.54	752.15	830.46	0.00	992.34	857.20	687.12	28.82
22	Sichuan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	Guizhou	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Yunnan	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Tibet	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Shaanxi	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	Gansu	W	171.03	139.20	148.45	140.88	135.99	105.79	140.22	90.56
28	Qinghai	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Ningxia	W	14.28	14.11	11.48	8.24	21.46	18.16	14.62	9.44
30	Xinjiang	W	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total								3317.62	Arena ratio
	East								778.78	23.47
	Central								2383.99	71.86
	West								154.84	4.67

Notes:
(1) The unit is million tons of water.
(2) E is the abbreviation for the east area, C is the abbreviation for the central area, and W is the abbreviation for the west area.
(3) Data for administration region Chongqing are regarded as part of Sichuan in this paper.

water is over-consumed for productive use. The other two regions having non-zero WATR are Shanxi (13) and Hennan (19). Their respective WATR are 2.23% and 3.61% and total reducible water amount is 2383.99 million tons, which is relatively small for both. The less efficient production processes and out-dated technology incorporated in their production are the main causes of resulting in this high WRT amount in this area. Importing advanced technologies and efficient production processes externally can reduce this redundant use portion of productive use water.

As stated previously, the west area has also a higher WATR for productive use than that of residential water, but its WATR for productive use keeps a low level compared to the central area. This is in relationship to this area recently focusing on development, and also the residences in this area are used to consuming water efficiently due to this area traditionally being a water drought area. Gansu (27) and Ningxia (29) are the two regions as main sources of generating areas' WATR. The former has on average 27.62% of WATR and the latter has on average 11.32% WATR in their productive use water amount. These two ratios refer to an average of 140.22 million tons and 14.62 million tons of water that need to be adjusted, which are still relatively small amounts to that in other regions or areas. It is noted that Gansu's WRT amount is 90.56% of the area's total and it may be related to the Yellow River passing this region.

Different from the result we got from WATR of residential water use amount, the WATR and WRT of productive water use amount are much higher. As we know that the manufacturing facilities have been established on a massive scale and all kinds of production are increasing at a surprising scale in China, the natural resources are therefore consumed unrestrictedly without appropriate plans. Water resources are one of these natural resources which have been over-consumed to support this great economic development in China. All these scenarios result in different results between the WATR of residential use portion and that of productive use portion.

Water efficiency vs. regional development

We sum the areas' WRT from both residential use water and productive use water. The total adjustment amount of WRT in the three areas is obtained, as shown in Fig. 3. In this figure, we find the total WRT of the central area is the dominant portion of China's total during the research years. It is about three-fourths of China's total. The other portion is composed of WRT from the east and west areas, which are relatively small especially for WRT of the west area.

The WATR reveals the inefficient portion of water use in each region. When a region is capable of reducing and adjusting this inefficient portion of water use, the water use efficiency shall reach the optimal level located at the frontier position identified by DEA. Therefore, the total-factor water efficiency (WE) of the region is explained by the complementary part of WATR, which is shown in Eq. (4) below:

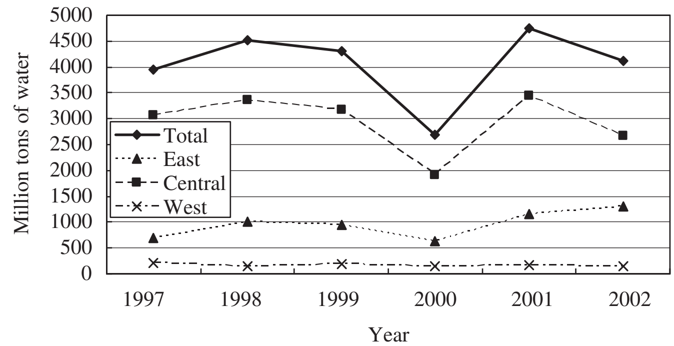


Fig. 3. Total adjustment amount of water use by area and year (1997–2002).

$$\mathrm{WE} = 1 - \mathrm{WATR}. \tag{4}$$

Based on Eq. (4), the WE of China's total is computed as 81.56%. By the same computation, the WE scores are 95.67%, 79.80%, and 96.76% in the east, central, and west areas' respectively. As shown in Fig. 4, a U-shape relation exists between the total-factor water efficiency and per capita real income in an area.

The east area has the highest per capita real income at an average of 1000.74 RMB and the second best efficient water use condition in China. The west area has the highest water efficiency result, but this area actually just started its area development recently. Therefore, the area has the lowest level of per capita real income which is on average of 543.5 RMB. The central area has the second highest level of per capita real income, at an average of 595.2 RMB. However, it has the lowest water efficiency among all areas. This area has roughly three-fourths the ratio of China's WRT in the research period that needs to be further reduced and adjusted. The discovered U-shape relation conforms to the reality in China that out-dated production processes and production technology does produce not only the total adjustment amount of water, but also generates a deteriorating environmental quality.

Since regions of the east area reach a high level of per capita real income, water efficiency and environmental quality have both become the focus. Therefore, the east area adopts more efficient production processes and up-to-date technology. This area's WE has also significantly improved. The worst WE appear in the central area where inefficient production processes need to be significantly improved. As with the U-shape curve shown in Fig. 4, WE declines dramatically in a short time at the beginning when development starts, however, it takes a much longer period to recover back to the original level following the economic development. This result shows that consumption of water resources in the beginning of development in an area should be placed at a higher level of concern so that a serious deterioration of WE can possibly be controlled and

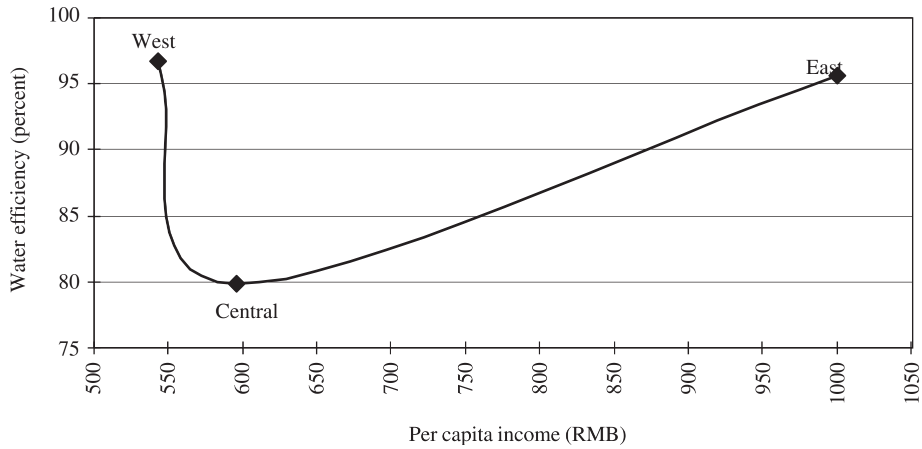


Fig. 4. The U-shape relation between the eight-year average total-factor water efficiency and per capita real income of areas in China.

reduced. The WATR needs to further reduce in order to reach sustainability of economic development.

Concluding remarks

The WATR is first constructed in this study as an index to evaluate regional water efficiency in a framework of total factor production. The production frontier is constructed by DEA including water as an input in company with conventional inputs used in an economic analysis such as labor employment and capital stock. The target water input is computed by DEA by each region and the index WATR is therefore calculated by dividing the target water input by the actual water input. Eqs. (3) and (4) explain how this index is constructed in detail. Water input data are collected from two parts of water use: residential use water and productive use water. These data enable our study to understand WATR at these two kinds of water use, respectively. A U-shape relation between the regional total-factor water efficiency and per capita real income in China is discovered, conforming to the environmental Kuznets curve (EKC) theory shown in Fig. 4.

The famous EKC postulates an inverted-U relationship between economic development and environmental quality. It suggests that environmental degradation should increase at low incomes, reach a peak (turning point), and eventually decrease at high incomes. The EKC theory implies that persistent economic growth can be accompanied by reductions of environmental degradation in the long run (Neumayer, 1999). The other optimistic view, the Porter hypothesis, states that reducing the environmental impacts of production will improve productivity, hence simultaneously benefiting economic growth and the environment (Porter and van der Linde, 1995). Furthermore, more profitable firms are more likely to adopt cleaner technologies (Dasgupta et al., 2002).

The index WATR shows regional water efficiency based on China's own frontier, but not on that for the other economies. The multiple-input production model is adopted in this study since water alone cannot produce any outputs and it has to be accompanied by other inputs to produce real outputs, though water is an essential factor for economic production. On the other hand, a certain portion of GDP output is generated not only by labor and capital stock, but also by water input. With a multiple-input model considered in a production function, the efficiency can therefore be evaluated in a more appropriate approach.

From the analysis result obtained from using the index WATR, the central area has the worst ranking of water efficiency in China and contains the most water reducible amount which is around three-fourths of China's total. The adjustment amount of productive use water is the major portion of this amount as it can be seen in Fig. 3. The reason behind this result is due to less efficient production processes and technical lags do exist in the central area. The efficiency of productive use water needs to improve with major attention in this area. The total adjustment amounts of water use in the east area and the west area are relatively low compared to that of the central area, but these two areas have high WATR for productive use water. The east area consumes the most water amount in China; however, water consumption in this area is at a high efficiency level. This result shows that water efficiency can be improved with appropriate policies and plans, so that the high efficient water use condition can be performed on the consumption of both residential and productive use water.

A U-shape relation is discovered between the ratio of the regional total water efficiency and per capita real income in China. This finding discloses that the WATR is an effective ratio to evaluate water efficiency among regions with a viewpoint towards total factor production. The developed area (the east area) in China has a higher per capita real income. Its water efficiency has already been a major concern for improvement. However, this case does not happen for the mild-developed area (the central area) in China, because this area consumes the second largest amount of water, but at low efficiency. The regional performance of water use can be illustrated by the index WATR. The regions owning major adjustment amounts in the area can be identified from this index as a reference for further study at a deeper level.

Sustainability of economic development is a target to reach from the national level to the regional level. Sufficient water supply is essential in order to reach this goal since it is a finite and essential resource for production, development, and lives on this planet. This study reviews water efficiency in China by using a newly introduced index WATR. The same analysis should be applied to major economies in the world so that a global water input frontier can be constructed. The index WATR is then based on the global frontier to evaluate water efficiency among major economies. Further studying may induce the next step in water saving at the economy level, such that the optimal condition of water use can be formed here on earth. The goal of sustainable development can indeed become feasible in terms of water use.

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