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Water congestion efficiency of regions in China

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Abstract: This study measures the water congestion efficiency of 30 regions in China during 2003 to 2012, using the data envelopment analysis (DEA) approach. The results show that 23 out of 30 regions face a situation of congestion. For all types of water use, the water efficiency of consumption water is better than ecological protection water, which is better than industry water, whereas agriculture water shows the most serious input congestion. In order to improve water efficiency, China should place greater emphasis on water savings, apply new technologies, and revise its regional development planning.

Key words: Water efficiency, input congestion, data envelopment analysis

1. INTRODUCTION

Water plays an irreplaceable role in people's daily life, and for a large populous country like China that has abundant productive labor and various industries, how to make good use of this precious natural resource is a serious issue. In recent years, global warming and climate change have become a huge challenge for many governments around the world to deal with. Fierce and extreme weather events can bring about mudslides, floods, and cloudbursts, yet unfortunately it is difficult to store the huge amount of rainfall from these events. In contrast, these unpredictable events can cause water shortages and water pollution, affecting people's lives, industry, and agriculture, not to mention the extra efforts that need to be made for ecological protection. Due to the change of the spatial distribution of water resources, climate change may also influence the balance capacity between supply and demand (Proença de Oliveria et al. 2015). To sustain welfare and economic growth, an appropriate water resource policy is essential, especially when trying to improve the efficiency of all kinds of water usage.

Although China has the fifth largest renewable water resources at 2,840 cubic kilometers in the world in 2011 (CIA 2011), it still is confronting a renewable freshwater shortage problem. According to the World Bank, China's renewable internal freshwater resources per capita totaled 4,225 cubic meters in 1962, but dropped to 2,062 cubic meters in 2014 (World Bank 2014). The stress of its worsening water usage efficiency needs urgent improvement. Moreover, another challenge for China is that its water resources are unevenly distributed between the South and the North, and therefore the country has started up the South-to-North Water Diversion (SNWD) project. Three routes (eastern, central, and western) are separately being implemented in order to relieve the domestic water usage pressure (SNWD 2016). It is necessary for China to investigate the level of water consumption situation in regions to sustain prospective water usage (Yao et al. 2017).

To deal with the scarcity of water resources, China has set up a number of policy goals and priorities for water resource management. Through its 13th Five-Year Plan (2016-2020), the Chinese government is focusing on total water resource utilization control, water environment protection, and water pollution control management in order to improve the efficiency of resource usage and the level of ecological protection of various resources (Xinhuanet 2015). To achieve this goal, regional development planning is essential for the even distribution of different business sectors and industries. Besides, a well-planned hydrologic infrastructure in regions would ensure water resources remained in proper preservation and improved (Padowski et al. 2016). Because water resources are highly related to annual economic growth, it is worthwhile to understand water usage efficiency among the regions of China (Hu et al. 2006).

After separating water use into three sectors (agricultural sector, industrial sector, and domestic sector), industrial and domestic water usages have shown a rapidly increasing trend and higher growth rates since 1993. Under the constraint of limited water resources, China's agricultural sector is under serious pressure when competing for its own water resources (Yan et al. 2015). The situation has raised concern about water resource management in China from the public (Pu et al. 2015). Moreover, with the increasing trend of industrialization and urbanization, the water use conflict between the industrial and domestic sectors has become a severe hindrance to sustainable development (Li et al. 2015). Strengthening water use efficiency is extremely vital to deal with the growing water scarcity, and it is becoming more and more important to explore empirical data of water use efficiency to provide supportive reference for water resource management decision making (Yan et al. 2014).

Because water is such a vital and necessary resource, many studies have shown great interest in resolving the shortage and waste problem. Hu et al. (2006) were the first to mention the total-factor water efficiency of regions in China, using a multiple-input model to evaluate water efficiency in a region. Their paper established regional targets of water input, including residential and productive water use, as found through DEA and the index of a water adjustment target ratio (WATR). Wang (2010) used DEA to develop farm-level technical efficiency measures and sub-vector efficiencies for irrigation water use. Tobit regression was subsequently adopted to detect which factors influence irrigation water efficiency under the shortage of water resources. Li et al. (2013) analyzed Beijing's environmental efficiency and related factors by using a two-step DEA method that considers undesirable outputs. Bian et al. (2014) applied proposed models based on the concept of the DEA approach to analyze the efficiencies of regional urban water use and wastewater decontamination systems in China.

The scarcity problem of water resources could be the negative factor for future economic growth (Li and Phillips 2017). Thus, a water shortage crisis is an issue that everyone should be aware of. Various research studies of water efficiency in other countries have adopted the DEA method. Thanassoulis (2000) employed it to rearrange water distribution by evaluating the efficiencies of UK water utilities. Lilienfeld and Asmild (2007) applied the DEA approach to estimate the excess water use in irrigated agriculture in western Kansas between 1992 and 1999. Byrnes et al. (2010) used standard DEA models to analyze the efficiencies of urban water utilities in the regions of New South Wales and Victoria.

This study investigates the congestion efficiencies of water use in China during 2003-2012. Data envelopment analysis (DEA) is adopted to estimate the input congestion efficiencies and to disaggregate water efficiency scores. The research then explores for a deeper understanding of the localized water congestion issue by looking into regional policy and breaking down industry in the target cities. The results contribute to finding out the reasons for resource input congestion and provide solutions for improving water efficiency.

2. RESEARCH METHODOLOGY

To measure the congestion effect, we adopt the two-stage method by Tone and Sahoo (2004). Figure 1 exhibits the phenomenon of congestion where we can see increasing input x leads to a decrease in output y at points F and G.

The first stage employs the output-oriented VRS DEA model (BCC-O) to estimate the congestion of inputs. For the purpose of investigating the situation of congestion, Tone and Sahoo (2004) assumed the production possibility set as follows:

$$P_{convex} = \{(x, y) | x = X\lambda, y \leq Y\lambda, \sum \lambda = 1, \lambda \geq 0\} \tag{1}$$

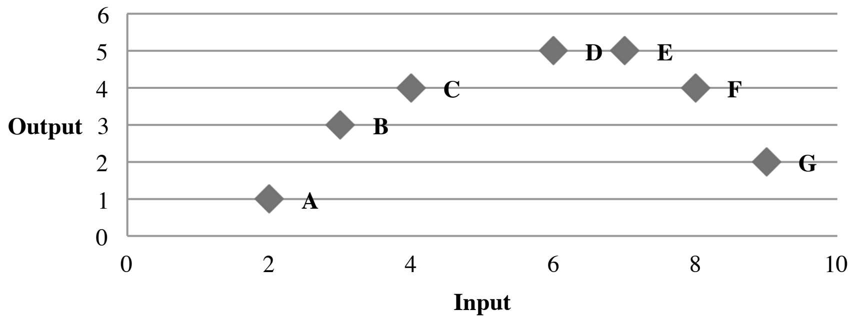

Figure 1. Congestion (source: Tone and Sahoo 2004)

They assumed that $(x_i, y_{i)}$ is P_{convex}-efficient, which means the following model has an optimal solution $(\emptyset^* = 1, q^{+*} = 0)$. The congestion-strong model is as follows:

$$max_{\emptyset,\lambda}\ \emptyset$$

$$\text{s.t. } -\emptyset y_i = Y\lambda - q^+ \tag{2}$$

$$x_i = X\lambda$$

$$\sum_{i=1}^{I} \lambda_i = 1$$

$$\lambda \geq 0$$

$$q^+ \geq 0$$

If $(x_i, y_{i)}$ is not P_{convex}-efficient, then they project (x_i, y_i) onto the P_{convex} frontier by the following formula:

$$y_i{}^* \leftarrow \emptyset^* y_i + q^{+*} \tag{3}$$

They then applied the following two-step procedure to the projected DMU.

Step 1: Compute the efficiency score by the BCC-O model (1) and then determine whether the congestion happens by the following three conditions. (A) If $\emptyset^* = 1, s^{-*} = 0, and\ s^{+*} = 0, then\ (x_i, y_i)$ is BBC-efficient, and it means there is no congestion. (B) If $\emptyset^* = 1, s^{-*} \neq 0$, and $s^{+*} = 0$, then (x_i, y_i) is technically inefficient, and it means that there are too many inputs of resources, but they do not affect the output. (C) If $\emptyset^* = 1,\ s^{-*} \neq 0\ or\ \emptyset^* > 1$, then (x_i, y_i) shows congestion.

Step 2: Calculate the upper bound scale elasticity ($\bar{\rho}$) by using the results of the BCC-O model. If $\bar{\rho} < 0, then\ (x_i, y_i)$ is strongly congested. If $\bar{\rho} \geq 0$, then (x_i, y_i) is weakly but not strongly congested. Symbols $s^+\ and\ s^-$ are the output and input slacks of the BCC-O model. Symbol q^+ is the output slack of the congestion-strong model.

Tone (2001) then used the slacks-based measures in the second stage to solve the congestion-weak model. The formulation is as follows:

$$\max \tfrac{1}{s}\textstyle\sum_{r=1}^{s} \frac{t_r^+}{y_{ro}} + \varepsilon \tfrac{1}{m}\textstyle\sum_{i=1}^{m} \frac{t_i^-}{x_{io}} \tag{4}$$

$$\text{s.t. } y_i = Y\lambda - t^+$$

$$x_i = X\lambda + t^-$$

$$\sum_{i=1}^{I} \lambda_i = 1$$

$$\lambda \geq 0, t^- \geq 0, t^+ \geq 0$$

Here, we assume that there are $M(i = 1, 2, \dots, m)$ inputs and $S(r = 1, 2, \dots, s)$ outputs for each DMU. Moreover, y_{r0} is the rth output of DMU O, and x_{i0} is the ith input of DMU O. Lastly, $t_r^+(r = 1, 2, \dots, s)$ and $t_i^-(i = 1, 2, \dots, m)$ correspond to the shortage of outputs and the amount of input congestion, and ε is a non-Archimedean small positive number.

To measure the room for improvement in water efficiency (WE), we apply the Water Adjustment Target Ratio (WATR) formula proposed by Hu et al. (2006). The formula is as follows:

$$\text{WATR(i, t)} = \text{Water reduction target(i, t)} / \text{Actual water input(i, t)} \quad (5)$$

which is in the i-th region and the t-th year.

$$\text{WE} = 1\text{-WATR} = \text{Target water input(i, t)} / \text{Actual water input(i, t)} \quad (6)$$

By converting the regional water reduction target into the index of WE, we are able to compare the ratio between regions directly without considering different sizes and scales of the economy. The values fall between zero and one. A WE value of one means an efficient production situation in that region and no water input amount needs to be saved.

3. DATA AND VARIABLES

This paper establishes a dataset on 30 regions in China during 2003 to 2012. The thirty regions are divided into three main areas: east, central, and west. This classification was derived from the 7th Five-Year Plan (1986-1990) (People's Daily Online 2016). After the adjustment of GDP per capita in 2000, the east and west areas respectively consist of 11 regions, and the other 8 regions are in the central area as shown in Figure 2.

East Area (11 Regions)			Central Area (8 Regions)		West Area (11 Regions)		
1.Beijing	5.Shanghai	9.Shandong	12.Shanxi	16.Jiangxi	20.Guangxi	24.Guizhou	28.Qinghai
2.Tianjin	6.Jiangsu	10.Guangdong	13.Jilin	17.Henan	21.Inner Mongolia	25.Yunnan	29.Ningxia
3.Hebei	7.Zhejiang	11.Hainan	14.Heilongjiang	18.Hubei	22.Chongqing	26.Shaanxi	30.Xinjiang
4.Liaoning	8.Fujian		15.Anhui	19.Hunan	23.Sichuan	27.Gansu	

Figure 2. The administrative regions and three major areas in China

There are six inputs (Regional labor employment, Real capital stock, and Agriculture water consumption, Industry water consumption, Private water consumption and Ecological protection consumption) and one output (Regional GDP) in the DEA model. Inputs are collected from different sources. Regional labor employment is collected from China Labour Statistical Yearbook (China Statistical Yearbooks Database 2016), while the others are collected from China Statistical Yearbook published by the National Bureau of Statistics of China (NBS 2016). Data of capital stock are not available in any statistical yearbook of China. In this study, real capital stock is recalculated each year based on the following formula (Li et al. 2013):

Capital stock in the current year
= capital stock (previous year)
+ capital formation (current year)
- capital depreciation (current year)

The approach of estimating the initial capital stock in 2013 is based on Harberger (1978).

$$K_{t-1} = \frac{I_t}{g_{GDP}+\delta} \tag{7}$$

Here, K equals the capital stock of the period; I is the capital formation amount; g represents the GDP growth rate; and δ equals the rate of capital depreciation.

Regional water use is separated into four parts, Agriculture, Industry, Consumption, and Ecological protection, in terms of the classification in the China Statistical Yearbook (NBS 2016). The single output, Regional GDP, is also collected from the China Statistical Yearbook (NBS 2016) and deflated to 2010 values.

Table 1 shows the summary statistics of the aforementioned inputs and output, including water use as an input that is ordered by regions and areas. The mean GDP is 2.18 trillion RMB in the east area, which is higher than 1.22 trillion RMB of the central area and much higher than 0.71 trillion RMB of the west area during the sample years. Compared to the mean GDP of China from Hu, Wang and Yeh (2006) during 1997-2002, this study finds that the poverty gap is getting narrower and the standard deviation in the central area is turning lower. For production inputs, the east area has the highest capital stock. The mean of capital stock of the east area is 5.81 trillion RMB, or around 1.5 and 2 times greater than the central and west areas, which are 3.95 and 2.79 trillion RMB, respectively. The input of labor employment is concentrated in the east area at about 10 million persons. The labor employment is not too much different between the central and west areas. The west area has the least labor employment since this area is less developed.

Table 2 provides a correlation matrix. All inputs have positive correlation coefficients with the output, which mean that all inputs satisfy the isotonicity property with the output. Industry water and consumption water have a relatively high correlation coefficient against GDP at 0.648 and 0.775, respectively. The reason why agriculture water and ecological protection water have low correlation coefficients is because the value of production on these two water usages is much lower than other two water usages. From the results of the inputs and output correlation matrix, water input efficiency is analyzed herein in order to understand individual water efficiency states among all regions of China.

4. EMPIRICAL FINDINGS

As Table 3 shows, during 2003 to 2012 seven regions (Beijing, Tianjin, Shanghai, Shandong, Guangdong, Qinghai, and Ningxia) had no input congestions, with five of them in the east area and two of them in the west area. The empirical finding shows that water input congestion is a long-term problem and need to be solved by efficiently using (saving) water in China.

Table 1. Summary statistics of output and input factors by region (2003-2012)

Region		Output		Input											
		Real GDP (Base=2010, 100mn RMB)		Capital (Base=2010, 100mn RMB)		Labor (10,000 persons)		Water Use (100 million cu.m) Agriculture		Industry		Consumption		Ecological Protection	
		Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev	Mean	STDev
Beijing	E	13658.98	3419.04	41559.36	8623.51	856.99	134.04	11.60	1.13	5.95	1.07	14.65	0.97	2.78	1.60
Tianjin	E	8366.10	3040.39	31015.68	6342.58	302.04	65.36	12.34	1.11	4.60	0.41	4.86	0.42	0.79	0.40
Hebei	E	19693.71	5299.48	59136.34	20061.91	775.28	127.20	146.86	3.81	24.86	1.18	23.52	0.73	2.32	1.01
Liaoning	E	17203.13	5233.35	52895.16	16973.61	969.02	125.00	89.28	2.83	23.23	1.76	24.26	0.82	2.35	1.37
Shanghai	E	16723.33	4106.21	49005.12	12529.65	692.91	132.23	17.28	0.96	79.70	4.55	21.66	2.17	1.44	0.53
Jiangsu	E	38913.49	11581.29	100675.92	42665.96	1631.93	475.62	281.59	25.90	197.27	19.98	47.53	4.88	8.38	5.39
Zhejiang	E	26637.63	6961.02	72258.40	28335.60	1321.19	426.62	100.20	6.19	59.24	3.10	35.26	4.20	11.40	4.29
Fujian	E	13849.52	4198.63	41474.73	8673.17	730.60	221.51	99.29	3.15	71.34	8.32	22.13	2.41	1.48	0.58
Shandong	E	30152.18	17391.90	97303.06	42117.72	1102.11	585.97	106.89	63.15	22.03	6.86	23.96	12.97	2.66	2.32
Guangdong	E	41913.85	13569.45	78973.94	34054.00	1876.37	616.17	202.13	36.81	89.97	56.86	66.85	30.97	5.35	2.71
Hainan	E	12591.38	13713.86	14787.58	15065.17	781.96	827.93	113.05	101.31	57.15	68.58	39.40	42.69	2.13	2.53
Shanxi	C	7057.00	4192.02	33849.37	12315.76	374.16	220.23	40.15	11.26	10.67	6.79	8.84	3.02	1.23	1.31
Jilin	C	8377.65	2729.17	33532.87	6811.10	484.03	108.76	87.73	52.88	25.05	11.37	13.96	2.51	2.80	1.68
Heilongjiang	C	9735.53	2729.15	28991.43	6551.24	705.09	85.34	201.95	69.12	49.78	14.59	17.73	2.96	2.20	1.70
Anhui	C	11641.22	3558.69	32031.72	5055.59	652.25	137.17	139.66	26.20	82.39	13.56	26.89	3.18	1.81	1.15
Jiangxi	C	8891.78	2660.10	28616.39	4763.72	529.31	102.67	141.54	16.57	54.59	4.39	23.76	2.79	2.35	1.35
Henan	C	21970.65	6371.02	74938.90	31963.54	1035.97	180.24	127.10	9.50	50.22	6.71	34.00	1.69	5.82	2.51
Hubei	C	14936.21	4650.57	42456.95	9276.12	869.21	188.46	140.08	5.72	98.29	15.63	30.07	1.62	0.15	0.08
Hunan	C	14952.01	4633.96	41566.97	10904.51	794.97	167.62	194.74	7.94	83.29	8.06	43.81	2.50	2.98	0.55
Guangxi	W	8927.41	2751.44	38098.33	13883.32	498.64	86.42	207.09	10.92	48.56	6.10	42.61	6.20	4.40	1.17
Inner Mongolia	W	10395.43	3919.78	38549.57	13319.95	419.39	75.77	140.07	5.45	17.79	5.08	12.96	1.97	6.93	4.24
Chongqing	W	7317.49	2499.31	25653.68	5633.41	473.74	159.00	20.20	2.01	39.81	7.49	17.12	1.19	0.47	0.14
Sichuan	W	18104.06	6422.76	43964.58	8593.33	916.01	149.11	124.21	8.56	58.57	2.94	35.14	3.82	2.00	0.25
Guizhou	W	4440.87	1324.79	20072.14	10895.80	308.68	49.99	50.77	1.86	31.67	4.36	15.94	1.48	0.54	0.14
Yunnan	W	7023.34	1958.92	33236.56	7145.87	535.33	149.22	104.22	5.17	21.80	3.64	20.60	2.03	2.10	1.40
Shaanxi	W	9388.43	3088.13	35638.83	7226.39	512.39	80.12	54.90	2.99	12.50	0.66	13.70	1.19	0.87	0.39
Gansu	W	4030.54	1085.17	19303.94	9513.86	292.45	33.99	95.30	1.15	14.71	1.29	9.61	0.85	2.46	1.18
Qinghai	W	1279.37	385.32	12569.92	13613.01	88.56	11.44	21.99	0.86	4.98	2.00	3.15	0.39	0.43	0.32
Ningxia	W	1608.69	461.63	14027.72	12074.07	102.04	19.25	66.06	4.28	3.73	0.51	1.73	0.09	1.03	0.46
Xinjiang	W	5394.26	1374.46	25836.25	6277.44	384.04	39.33	482.97	30.30	9.70	1.51	12.25	1.28	20.79	6.78
	Total	13839.17	4107.21	42067.38	10661.43	700.56	195.75	120.71	24.51	45.11	15.32	23.60	9.16	3.41	1.63
	East	21791.21	5058.64	58098.66	13348.50	1003.67	258.32	107.32	32.92	57.76	24.03	29.46	14.27	3.73	1.61
	Central	12195.25	1291.49	39498.08	8910.12	680.62	47.68	134.12	23.57	56.78	4.20	24.88	0.59	2.42	0.74
	West	7082.72	1758.72	27904.68	3081.18	411.93	53.73	124.34	8.44	23.98	2.32	16.80	1.75	3.82	2.11

Table 2. Correlation matrix for output and inputs

				Water use			
	GDP	Capital	Labor	Agriculture	Industry	Consumption	Ecological Protection
GDP	1.000						
Capital	0.926	1.000					
Labor	0.965	0.851	1.000				
Water use - Agriculture	0.254	0.222	0.284	1.000			
Water use - Industry	0.648	0.525	0.675	0.352	1.000		
Water use - Consumption	0.775	0.598	0.834	0.392	0.725	1.000	
Water use - Ecological Protection	0.243	0.273	0.254	0.785	0.111	0.191	1.000

Table 4 shows the pure technical efficiency (PTE) scores of regions in China during 2003-2012. The average PTE score for the resources of China's regions is 0.897, showing that there is generally 10.30% room for resource savings in China. The annual average congestion PTE scores are 0.853 (2003), 0.851 (2004), 0.882 (2005), 0.896 (2006), 0.881 (2007), 0.927 (2008), 0.907 (2009), 0.904 (2010), 0.942 (2011), and 0.926 (2012). As a result, China's regions have a fluctuating upward trend in resource efficiency since 2003. Comparing the PTE scores of the three areas, the average PTE score for the east area is 0.973, showing only 2.7% room for resource savings. Figure 3 shows that the PTE score of the east area is higher than the other two areas.

Table 5 shows that the average congestion WE score for agriculture water use of China's regions during 2003-2012 is 0.754, denoting that there is 24.6% room for agriculture water use savings in China. Among all parts of water consumption, agriculture water use exhibits the most serious input congestion, indicating that the primary task for improving China's water consumption efficiency is to improve agriculture water use efficiency.

Table 3. Input congestion statuses for regions in China during 2003-2012

Region		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Beijing	E	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Tianjin	E	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Hebei	E	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	Congested	Congested	Congested	Congested	Congested
Liaoning	E	BCC-efficient	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Shanghai	E	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Jiangsu	E	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	Congested	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Zhejiang	E	BCC-efficient	BCC-efficient	BCC-efficient	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Fujian	E	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Shandong	E	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Guangdong	E	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Hainan	E	Congested	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Shanxi	C	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	Congested	Congested	Congested	Congested	Congested
Jilin	C	BCC-efficient	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Heilongjiang	C	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Anhui	C	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Jiangxi	C	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Henan	C	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Hubei	C	Congested	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Hunan	C	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Guangxi	W	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Inner Mongolia	W	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Chongqing	W	Congested	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Sichuan	W	Congested	Congested	Congested	Congested	Congested	BCC-efficient	Congested	BCC-efficient	BCC-efficient	Congested
Guizhou	W	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	BCC-efficient
Yunnan	W	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Shaanxi	W	BCC-efficient	Congested	Congested	Congested	Congested	Congested	Congested	BCC-efficient	BCC-efficient	Congested
Gansu	W	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested
Qinghai	W	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Ningxia	W	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient	BCC-efficient
Xinjiang	W	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested	Congested

Note: Shadow indicates BCC-efficient.

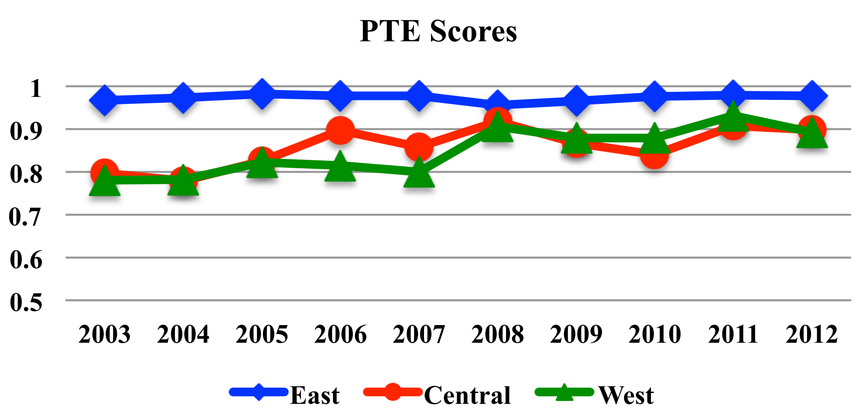

Figure 3. Comparison of PTE scores for areas

Table 4. Pure technical efficiency (PTE) scores for regions in China during 2003-2012

Region		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Beijing	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	E	1.000	1.000	1.000	1.000	1.000	0.995	0.849	0.986	0.988	0.964	0.978
Liaoning	E	1.000	0.846	0.895	0.943	0.965	0.721	0.909	0.884	0.915	0.979	0.906
Shanghai	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	E	1.000	1.000	1.000	1.000	1.000	0.996	1.000	1.000	1.000	1.000	1.000
Zhejiang	E	1.000	1.000	1.000	0.975	0.953	0.944	0.939	0.976	0.933	0.937	0.966
Fujian	E	0.895	0.858	0.904	0.830	0.840	0.857	0.921	0.894	0.937	0.872	0.881
Shandong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangdong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hainan	E	0.738	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.974
Shanxi	C	1.000	1.000	1.000	1.000	1.000	0.985	0.674	0.929	0.948	0.950	0.949
Jilin	C	1.000	0.811	0.873	0.966	0.954	0.984	0.784	0.956	0.957	0.865	0.915
Heilongjiang	C	0.472	0.500	0.686	0.978	0.906	0.912	0.907	0.794	0.960	0.894	0.801
Anhui	C	0.703	0.768	0.724	0.756	0.730	0.893	0.965	0.756	0.931	0.969	0.819
Jiangxi	C	0.718	0.655	0.646	0.826	0.640	0.819	0.880	0.728	0.817	0.867	0.760
Henan	C	0.798	0.795	0.956	0.902	0.854	0.860	0.801	0.821	0.803	0.786	0.838
Hubei	C	0.936	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.994
Hunan	C	0.744	0.701	0.719	0.753	0.776	0.888	0.927	0.738	0.836	0.860	0.794
Guangxi	W	0.665	0.647	0.697	0.700	0.680	0.757	0.746	0.657	0.666	0.680	0.690
Inner Mongolia	W	0.726	0.827	0.865	0.878	0.881	0.974	0.948	0.937	0.979	0.943	0.896
Chongqing	W	0.790	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.979
Sichuan	W	0.902	0.946	0.966	0.980	0.686	1.000	0.935	1.000	1.000	0.997	0.941
Guizhou	W	0.626	0.620	0.584	0.607	0.676	0.807	0.813	0.680	0.984	1.000	0.740
Yunnan	W	0.696	0.650	0.593	0.594	0.519	0.706	0.669	0.837	0.934	0.705	0.690
Shaanxi	W	1.000	0.636	0.888	0.727	0.836	0.914	0.991	1.000	1.000	0.872	0.886
Gansu	W	0.605	0.725	0.818	0.898	0.926	0.973	0.906	0.932	0.926	0.943	0.865
Qinghai	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ningxia	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Xinjiang	W	0.573	0.547	0.633	0.577	0.600	0.836	0.655	0.622	0.751	0.682	0.648
	Total	0.853	0.851	0.882	0.896	0.881	0.927	0.907	0.904	0.942	0.926	0.897
	East	0.967	0.973	0.982	0.977	0.978	0.956	0.965	0.976	0.979	0.978	0.973
	Centra	0.796	0.779	0.826	0.898	0.858	0.918	0.867	0.840	0.907	0.899	0.859
	West	0.780	0.782	0.822	0.815	0.800	0.906	0.878	0.879	0.931	0.893	0.849

Note: Shadow indicates congestion PTE score of one.

The annual average agriculture water use congestion WE scores are 0.773 (2003), 0.795 (2004), 0.808 (2005), 0.787 (2006), 0.737 (2007), 0.763 (2008), 0.742 (2009), 0.748 (2010), 0.719 (2011), and 0.667 (2012). Overall speaking, China's regions present a worsening-off trend in agriculture water use even through there are fluctuations during this period. One of the facts is that the rural areas in China have persistently grown high water-intensive crops. In this situation, famers require more water resources to sustain crop growth, but the value of crop productivity is low. Therefore, there is a serious input congestion in agriculture water use.

The price of agriculture water is also too low to encourage farmers to be efficient. Farmers are not charged volumetric prices, and so they have no reason to conserve water (Webber et al. 2008). Farmers as the end users make the decisions on how to use agriculture water, and thus they play an important role in the improvement of agriculture water use efficiency. Certain arrangements of exclusive water property rights and competitive water price mechanisms have effectively encouraged the water saving behavior of farmers (Wang 2010).

Comparing the agriculture water efficiency scores of the three areas, the average score for the east area is 0.937, showing only 6.3% room for water use savings. Figure 4 shows that the agriculture water use WE scores of the east area are obviously higher than those of the other two. Xinjiang (0.103), Guangxi (0.223) and Inner Mongolia (0.250) have the three worst efficiencies for agriculture water use. These three regions are all agriculture-dominated provinces.

Table 5. The congestion of agriculture water efficiency scores

Region		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Beijing	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	E	1.000	1.000	1.000	1.000	1.000	0.500	0.626	0.467	0.451	0.464	0.751
Liaoning	E	1.000	0.941	0.922	1.000	1.000	1.000	0.702	0.751	0.757	0.800	0.887
Shanghai	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	E	1.000	1.000	1.000	1.000	1.000	0.617	1.000	1.000	1.000	1.000	0.962
Zhejiang	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Fujian	E	0.512	0.585	0.707	0.873	0.462	0.704	0.978	0.886	0.705	0.682	0.709
Shandong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangdong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hainan	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shanxi	C	1.000	1.000	1.000	1.000	1.000	0.876	0.437	0.700	0.674	0.627	0.831
Jilin	C	1.000	1.000	1.000	0.526	0.471	0.858	0.179	0.546	0.483	0.309	0.637
Heilongjiang	C	0.535	0.418	0.584	0.442	0.397	0.406	0.897	0.317	0.112	0.108	0.421
Anhui	C	1.000	0.709	0.597	0.510	0.463	0.485	0.439	0.550	0.496	0.435	0.568
Jiangxi	C	0.401	0.484	0.405	0.428	0.301	0.443	0.364	0.459	0.452	0.430	0.417
Henan	C	1.000	1.000	1.000	1.000	1.000	0.755	0.776	0.810	0.838	0.798	0.898
Hubei	C	0.704	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.970
Hunan	C	0.360	0.558	0.581	0.549	0.367	0.472	0.432	0.538	0.452	0.395	0.470
Guangxi	W	0.279	0.313	0.190	0.194	0.200	0.323	0.187	0.213	0.179	0.157	0.223
Inner Mongolia	W	0.233	0.421	0.230	0.310	0.255	0.288	0.203	0.197	0.176	0.192	0.250
Chongqing	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sichuan	W	0.980	0.829	0.908	1.000	0.646	1.000	0.956	1.000	1.000	0.652	0.897
Guizhou	W	0.238	0.777	0.706	0.637	0.725	1.000	0.980	0.920	0.740	1.000	0.772
Yunnan	W	0.352	0.324	0.400	0.451	0.418	0.410	0.572	0.569	0.565	0.152	0.421
Shaanxi	W	1.000	0.939	0.900	0.912	0.748	1.000	1.000	1.000	1.000	0.431	0.893
Gansu	W	0.538	0.474	0.915	0.611	0.468	0.672	0.435	0.463	0.420	0.317	0.531
Qinghai	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ningxia	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Xinjiang	W	0.059	0.066	0.195	0.151	0.176	0.083	0.099	0.068	0.072	0.059	0.103
	Total	0.773	0.795	0.808	0.787	0.737	0.763	0.742	0.748	0.719	0.667	0.754
	East	0.956	0.957	0.966	0.988	0.951	0.893	0.937	0.919	0.901	0.904	0.937
	Central	0.750	0.771	0.771	0.682	0.625	0.662	0.566	0.615	0.563	0.513	0.652
	West	0.607	0.649	0.677	0.661	0.603	0.707	0.676	0.675	0.650	0.542	0.645

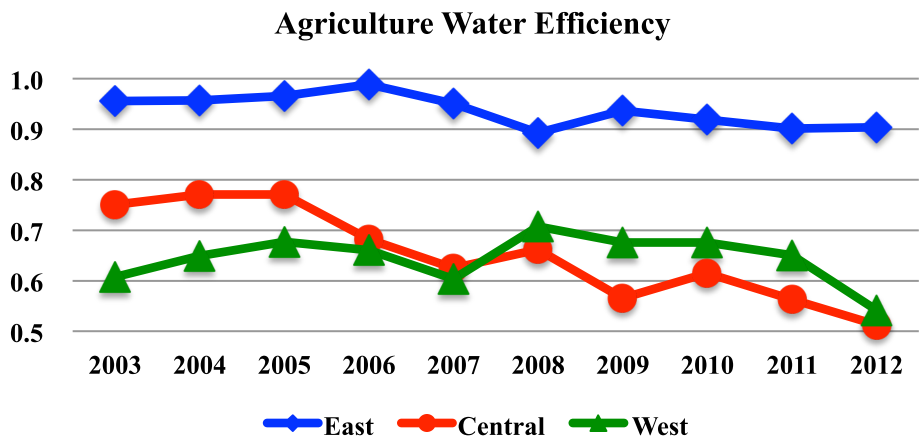

Figure 4. Comparison of agriculture water efficiency

In-migration to Xinjiang and Mongolia in the past thirty years has brought forth a significant increase in demand for food and triggered a series of irrigation-agriculture development projects to convert desert into farmland. Under such a policy, Xinjiang set up a goal of becoming an important agricultural zone in the area. Similarly, in Mongolia, there is also a tendency for shifting work resources from traditional animal husbandry into farming. Despite the fertile soil, the dry weather in these regions means that farming requires extra water input due to an unreasonable water use structure, weak cultivating and water preserving facilities, and zero sustainable concepts upon any project implementation.

Table 6 shows that the average congestion WE score for industry water use of China's regions during 2003-2012 is 0.820, meaning there is 18% room for industry water use savings in China. The annual average industry water use congestion WE scores are 0.854 (2003), 0.859 (2004), 0.824 (2005), 0.840 (2006), 0.824 (2007), 0.779 (2008), 0.788 (2009), 0.812 (2010), 0.812 (2011), and 0.811 (2012). Except for slight growth in the west area, the efficiencies of the east and central areas are declining during 2003 to 2012. In particular, the input congestion of the central area presents a marked deterioration.

Table 6. The congestion of industry water efficiency scores

Region		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Beijing	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	E	1.000	1.000	1.000	1.000	1.000	0.487	0.896	0.630	0.564	0.552	0.813
Liaoning	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shanghai	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	E	1.000	1.000	1.000	1.000	1.000	0.268	1.000	1.000	1.000	1.000	0.927
Zhejiang	E	1.000	1.000	1.000	0.993	0.745	0.785	1.000	1.000	0.960	0.832	0.931
Fujian	E	0.657	0.486	0.250	0.382	0.637	0.459	0.484	0.694	0.637	0.534	0.522
Shandong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangdong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hainan	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Shanxi	C	1.000	1.000	1.000	1.000	1.000	1.000	0.296	1.000	1.000	0.979	0.928
Jilin	C	1.000	1.000	0.731	0.723	0.497	0.632	0.350	0.702	0.692	0.652	0.698
Heilongjiang	C	0.581	0.303	0.470	0.888	0.870	0.497	1.000	0.512	0.635	0.655	0.641
Anhui	C	0.293	0.280	0.367	0.318	0.290	0.429	0.351	0.430	0.450	0.408	0.362
Jiangxi	C	0.757	0.365	0.467	0.461	0.367	0.577	0.510	0.533	0.587	0.512	0.514
Henan	C	1.000	1.000	1.000	0.684	0.373	0.321	0.332	0.337	0.346	0.341	0.573
Hubei	C	0.285	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.928
Hunan	C	0.852	0.721	0.460	0.417	0.320	0.590	0.524	0.531	0.524	0.483	0.542
Guangxi	W	1.000	0.952	0.480	0.431	0.397	0.552	0.346	0.258	0.153	0.166	0.474
Inner Mongolia	W	1.000	1.000	1.000	0.654	0.424	0.306	0.342	0.319	0.298	0.315	0.566
Chongqing	W	0.256	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.926
Sichuan	W	1.000	0.683	0.586	0.991	1.000	1.000	1.000	1.000	1.000	0.935	0.920
Guizhou	W	0.306	0.231	0.583	0.589	0.925	0.482	0.374	0.403	0.506	1.000	0.540
Yunnan	W	1.000	0.912	0.522	0.848	0.874	1.000	1.000	1.000	1.000	1.000	0.916
Shaanxi	W	1.000	0.836	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.984
Gansu	W	0.642	1.000	0.807	0.833	1.000	1.000	0.828	1.000	1.000	0.954	0.906
Qinghai	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ningxia	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Xinjiang	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
	Total	0.854	0.859	0.824	0.840	0.824	0.779	0.788	0.812	0.812	0.811	0.820
	East	0.969	0.953	0.932	0.943	0.944	0.818	0.944	0.938	0.924	0.902	0.927
	Central	0.721	0.709	0.687	0.687	0.590	0.631	0.545	0.631	0.654	0.629	0.648
	West	0.837	0.874	0.816	0.850	0.875	0.849	0.808	0.816	0.814	0.852	0.839

Industry water is overused for two main reasons. First, industrial water is provided at a low fixed price in China. This low price reduces companies' incentives to decrease their water usage. The second reason is the opportunity cost that results if the Chinese government restricts industrial water use. If manufacturing plants do not use sufficient water resources, they then need to decrease their factory operating ratios.

The southern provinces of China, which have abundant water resources, are unlikely to encounter water restrictions from the government. Thus, excessive industrial use of water resources is more serious in the southern provinces of China. The WE scores of industry water use in the five southern provinces, which are Fujian (0.552), Jiangxi (0.514), Hunan (0.513), Guizhou (0.540), and Guangxi (0.474), are far below the average.

Comparing the WE industry water use scores of the three areas, the average score for the central area is 0.648, showing only 35.2% room for water use savings. This indicates that improving industry water use efficiency is the most urgent task, versus the other types of water consumption, in the central area. Figure 5 shows that the industry water use WE scores of the central area are obviously lower than the others. Furthermore, the east area abnormally troughed out in 2008, because Jiangsu had congestion WE scores of one for its industry water use during 2003 to 2007, but its score subsequently dropped sharply to 0.268 in 2008.

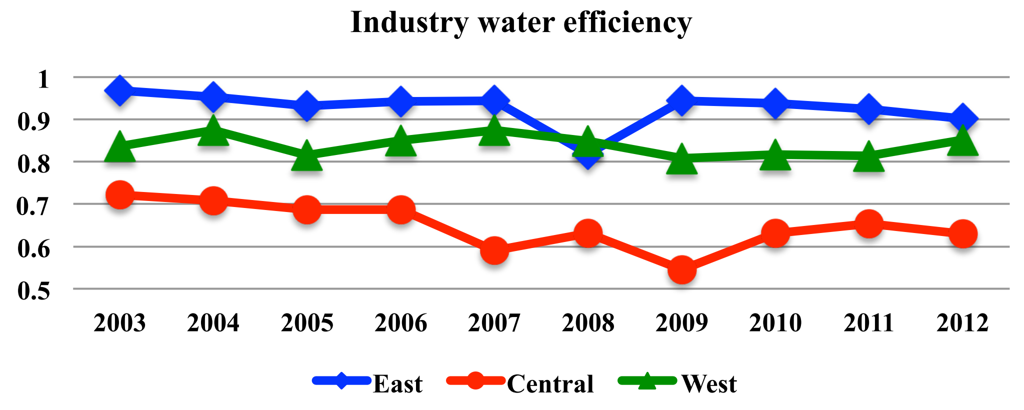

Figure 5. Comparison of industry water efficiency

Anhui (0.362), Guangxi (0.474), Jiangxi (0.514), Fujian (0.522), Guizhou (0.540), and Hunan (0.542) rank at the top for industrial water congestion. The lowest WE scores of industry water use region reside with Anhui (0.362). Industrial water use increased 22.63 billion cubic-meters in Anhui from 2002 to 2010, for a growth rate of 112.4%. Although Anhui has many water reservoirs, the provincial water distribution infrastructure is behind its demand, especially towards the northern part of the province. Another reason causing the industry water input congestion is that petrochemical and metal industries use a large amount of water, resulting in serious water pollution.

Guangxi is the second worst water efficiency province and is also a heavily concentrated by industry. The region contains metal forging, energy production and supply, and various high water usage and high pollution chemical industries. Wastewater, containing arsenic, lead, and cobalt, is released directly into water streams, risking the safety and health of provincial citizens. The image of the city is that of high pollution and high consumption industries.

Of particular note is that Jiangxi whose resources are highly concentrated in the mining industry. The province has Poyang Lake, the largest in China, but it still has periods of a super dry season and huge rainfall. In conclusion, high industrial water usage and high pollution lead to more water usage, thus mitigating environmental damage that is reflected in the water congestion efficiency measurements.

Table 7 shows that the average congestion WE score for consumption water use of China's regions during 2003-2012 is 0.875, pointing to 12.5% room for consumption water use savings in China. The congestion WE score of consumption water use is the highest among all types of water use. In other words, the most efficient water use is consumption water use in China during this period. Figure 6 shows that the consumption water use WE scores of the east area is the highest.

The annual average consumption water use congestion WE scores are 0.821 (2003), 0.868 (2004), 0.879 (2005), 0.899 (2006), 0.861 (2007), 0.874 (2008), 0.883 (2009), 0.885 (2010), 0.891 (2011), and 0.889 (2012). The annual average consumption water use congestion WE scores in the east area are all higher than 0.9 during 2003-2012. There are some slight ups and downs in the congestion WE scores of consumption water use for the central and west areas. The most crucial problem is the water price for a household. Low water prices provide little or no incentive to save water.

Comparing the WE consumption water use scores of the three areas, the east area (0.962) has the highest average WE of consumption water use score, implying only 3.8% room for consumption water use savings here. The WE of consumption water use score in the east and central areas fluctuated slightly over the decade. However, the WE of consumption water use score in the west presents slow growth.

Table 7. The congestion of consumption water efficiency scores

Region		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Beijing	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	E	1.000	1.000	1.000	1.000	1.000	0.711	1.000	0.738	0.708	0.669	0.883
Liaoning	E	1.000	0.728	0.703	0.949	0.963	0.974	1.000	0.952	0.882	0.928	0.908
Shanghai	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Zhejiang	E	1.000	1.000	1.000	1.000	0.825	0.804	0.866	0.953	0.826	0.722	0.900
Fujian	E	0.758	0.979	0.755	1.000	0.969	1.000	1.000	1.000	1.000	1.000	0.946
Shandong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangdong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hainan	E	0.449	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.945
Shanxi	C	1.000	1.000	1.000	1.000	1.000	0.822	0.632	1.000	1.000	1.000	0.945
Jilin	C	1.000	0.936	1.000	1.000	0.812	0.852	1.000	0.823	0.858	1.000	0.928
Heilongjiang	C	1.000	0.867	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.987
Anhui	C	0.798	0.664	0.767	0.806	0.721	0.801	0.846	0.862	0.980	0.895	0.814
Jiangxi	C	0.597	0.661	0.842	0.855	0.712	0.894	0.739	0.706	0.869	0.885	0.776
Henan	C	0.772	0.749	0.832	0.773	0.718	0.647	0.690	0.689	0.710	0.744	0.732
Hubei	C	0.763	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.976
Hunan	C	0.588	0.689	0.654	0.606	0.488	0.657	0.655	0.647	0.712	0.809	0.651
Guangxi	W	0.355	0.321	0.404	0.364	0.303	0.345	0.296	0.277	0.227	0.251	0.314
Inner Mongolia	W	0.813	0.960	0.859	0.757	0.603	0.540	0.604	0.585	0.547	0.748	0.702
Chongqing	W	0.417	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.942
Sichuan	W	0.963	0.899	0.883	0.976	0.820	1.000	0.902	1.000	1.000	0.872	0.931
Guizhou	W	0.323	0.499	0.606	0.608	0.686	0.767	0.789	0.698	0.713	1.000	0.669
Yunnan	W	0.506	0.633	0.515	0.669	0.768	0.743	0.840	0.808	0.870	0.605	0.696
Shaanxi	W	1.000	0.846	0.763	0.803	0.696	0.926	0.858	1.000	1.000	0.734	0.863
Gansu	W	1.000	1.000	1.000	1.000	0.971	0.977	1.000	1.000	1.000	0.955	0.990
Qinghai	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ningxia	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Xinjiang	W	0.536	0.619	0.788	0.800	0.787	0.746	0.778	0.801	0.833	0.855	0.754
	Total	0.821	0.868	0.879	0.899	0.861	0.874	0.883	0.885	0.891	0.889	0.875
	East	0.928	0.973	0.951	0.995	0.978	0.954	0.988	0.967	0.947	0.938	0.962
	Central	0.815	0.821	0.887	0.880	0.806	0.834	0.820	0.841	0.891	0.917	0.851
	West	0.719	0.798	0.802	0.816	0.785	0.822	0.824	0.834	0.836	0.820	0.806

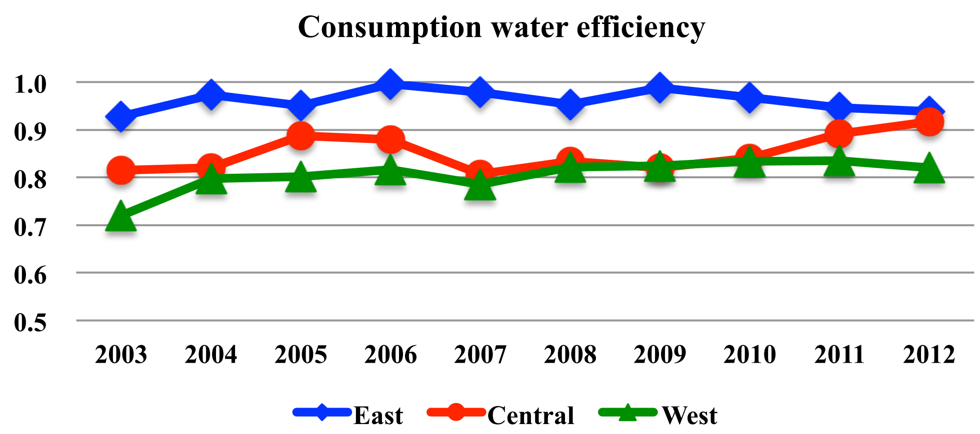

Figure 6. Comparison of consumption water efficiency

Guangxi (0.314), Hunan (0.651), Guizhou (0.669), and Yunnan (0.696) have the worst input congestion of consumption water use and all of them are located on the Yunnan-Guizhou Plateau. The common geological property of this plateau is karst topography (limestone) with a rugged landscape and constant fluviraption. Therefore, the surface ground is thin, which makes the preservation of water difficult despite high rainfall. On the Yunnan-Guizhou plateau, residents have more water to use, but also waste more water. During the transportation of water there exist some leakages due to worn equipment, and industrial water and agricultural water are polluted by colored metal and disposal of household products, respectively.

Guanxi has four main rivers flowing through it: Yu River, Qian River, Gui River and Lijiang River. However, the uneven rainfall season and inefficient rainfall lead to the problem of unstable water supply. One of the biggest reasons for input congestion can be recognized as wastage of industrial and consumer water. The consumption water input congestion implies that water is an excessive input.

Water is essential for socioeconomic development and for maintaining healthy ecosystems. Ecological protection water is for protecting water resources while at the same time allowing for development that is ecologically sustainable. From the view of ecology, environment and water resources are both important and influence each other.

Table 8 shows that the average congestion WE scores for ecological protection water use of China's regions during 2003-2012 is 0.820, meaning 18% room for ecological protection water use savings in China. The annual average ecological protection water use congestion WE scores are 0.952 (2003), 0.964 (2004), 0.849 (2005), 0.781 (2006), 0.782 (2007), 0.771 (2008), 0.793 (2009), 0.750 (2010), 0.780 (2011) and 0.775 (2012). The average WE scores of ecological protection water use are only better than the average WE scores of agriculture water use. We may conclude that ecological protection water use in China does not achieve the purpose of protecting water resources; on the contrary, it causes more water input congestion.

Table 8. The congestion of ecological protection water efficiency scores

Region		2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Average
Beijing	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Tianjin	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hebei	E	1.000	1.000	1.000	1.000	1.000	0.598	1.000	0.870	0.852	0.903	0.922
Liaoning	E	1.000	1.000	1.000	0.929	0.867	0.908	1.000	0.976	0.826	0.773	0.928
Shanghai	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Jiangsu	E	1.000	1.000	1.000	1.000	1.000	0.377	1.000	1.000	1.000	1.000	0.938
Zhejiang	E	1.000	1.000	1.000	0.204	0.182	0.128	0.402	0.435	0.344	0.864	0.556
Fujian	E	1.000	1.000	1.000	0.885	1.000	1.000	1.000	1.000	1.000	0.762	0.965
Shandong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Guangdong	E	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hainan	E	0.560	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.956
Shanxi	C	1.000	1.000	1.000	1.000	1.000	1.000	0.634	0.581	0.606	0.512	0.833
Jilin	C	1.000	0.894	0.601	0.435	0.440	0.717	0.573	0.402	0.504	0.249	0.582
Heilongjiang	C	0.980	1.000	0.428	1.000	1.000	0.867	1.000	0.942	0.682	0.248	0.815
Anhui	C	1.000	1.000	1.000	0.818	0.939	1.000	1.000	0.605	1.000	0.388	0.875
Jiangxi	C	1.000	1.000	0.955	0.832	0.646	0.951	0.450	0.372	0.658	0.757	0.762
Henan	C	1.000	1.000	1.000	0.469	0.431	0.323	0.467	0.460	0.470	0.470	0.609
Hubei	C	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Hunan	C	1.000	1.000	0.671	0.445	0.559	0.646	0.884	0.617	1.000	1.000	0.782
Guangxi	W	1.000	1.000	0.301	0.264	0.212	0.245	0.325	0.323	0.333	0.733	0.474
Inner Mongolia	W	1.000	1.000	0.151	0.105	0.126	0.175	0.186	0.162	0.153	0.128	0.319
Chongqing	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sichuan	W	1.000	1.000	1.000	0.850	1.000	1.000	1.000	1.000	1.000	1.000	0.985
Guizhou	W	1.000	1.000	1.000	0.937	1.000	1.000	1.000	1.000	1.000	1.000	0.994
Yunnan	W	1.000	1.000	1.000	0.952	0.688	0.581	0.576	0.463	0.498	1.000	0.776
Shaanxi	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Gansu	W	1.000	1.000	0.316	0.273	0.313	0.521	0.244	0.262	0.441	0.184	0.455
Qinghai	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Ningxia	W	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Xinjiang	W	0.024	0.033	0.039	0.041	0.072	0.091	0.056	0.041	0.037	0.291	0.072
	Total	0.952	0.964	0.849	0.781	0.782	0.771	0.793	0.750	0.780	0.775	0.820
	East	0.960	1.000	1.000	0.911	0.914	0.819	0.946	0.935	0.911	0.936	0.933
	Central	0.998	0.987	0.832	0.750	0.752	0.813	0.751	0.622	0.740	0.578	0.782
	West	0.911	0.912	0.710	0.675	0.674	0.692	0.672	0.659	0.678	0.758	0.734

Figure 7 also shows the ecological protection water use WE scores of the three areas. Among ecological protection WE scores of the three areas, the east area (0.933) has the highest average with only 6.7% room for ecological protection water use savings here. The WE of ecological protection water use score in the central and west areas declined rapidly in 2004, with the west area having the worst average WE of ecological protection water use score in 2003-2012. However, these scores go beyond the central area and into 2010 and 2012. The inefficient ecological protection water use in the central area in 2010 could be attributed to the Three Gorges Project on the Yangtze River. The WE of ecological protection water use score in Anhui and Jiangxi significantly decreased, but Jilin and Heilongjiang caused the inefficiency of ecological protection water use in the central area as a result of Russia's industrial water pollution that damaged the ecological system.

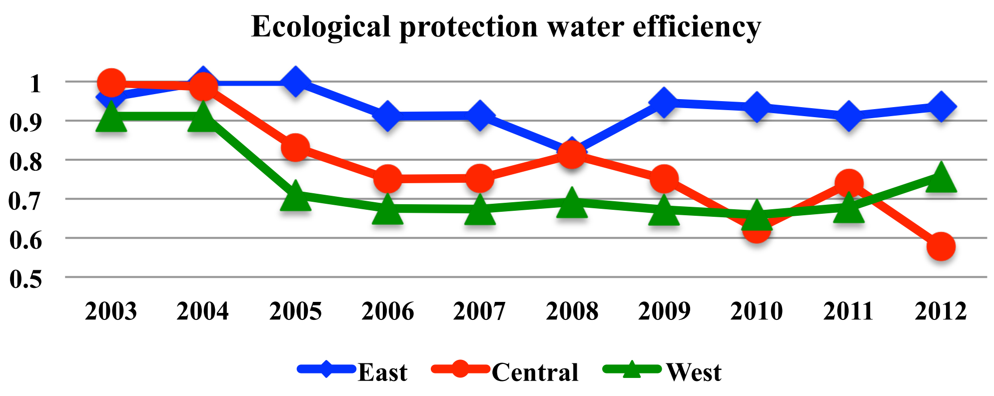

Figure 7. Comparison of ecological protection water efficiency

Xinjiang (0.072), Inner Mongolia (0.319) and Gansu (0.455) have the lowest average WE ecological protection water use scores. These provinces have an arid ecological environment with a fragile ecological system. Due to the sandy soil, under plantation, and low rainfall, water resources there are short both in quantity and in quality. This causes a series of ecological and environmental problems.

The consequence of ecological environment deterioration is serious poor water quality and a great loss of both water and soil that further degrade the quantity and quality of future water resources. This in turn makes the supply of ecological water scarce and gradually destroys the ecological system, not to mention that water pollution and water waste also speed up the process. To deal with these problems, residents have increased their consumption of surface water and exploitation of ground water much more, instead of saving and protecting this resource. The vicious cycle is not only bringing about ecological protection water input congestion, but is also seriously damaging the local ecological system.

5. CONCLUSION

Based on this study's results, only 7 regions in China had no input congestion during 2003-2012, among which 57.33% of China's regions had been using too many inputs, such that their outputs began to decline with increases in the inputs. The average congestion PTE score for resource use in China's regions during 2003-2012 is 0.897, showing 10.31% room for resource savings in China.

The average congestion WE scores during 2003-2012 are: Agriculture water use (0.754), Ecological protection water use (0.820), Industry water use (0.820), and Consumption water use (0.875). These disaggregate WE scores show that improving the efficiency of agriculture water use and ecological water use is relatively more urgent for China's regions.

To improve the current management for more effective water use, this study offers suggestions that can be applied to places with similar water congestion issues. In China, about half of cultivated land is "weather dependent" (no irrigating facility, no flood and drought proof, and highly dependent on rain water for cultivation). Generally speaking, half of the farmlands lack basic irrigating equipment. The current progress of scientific technology could help overcome climate difficulties, especially as there are many topographical zones in China that make it hard to generalize and present a single solution. This is why water facility technology is important to help breach the natural limitations and to fit the different regions.

For future management improvement, there are some challenges the authorities need to face. China's water facilities generally exhibit the "Last Mile" issue. Put differently, most of the trenches were built in the 1960s and 1970s with low construction standards and a lack of planning, and some were even incomplete. Under resource and financial constraints, there was a successful example in Anhui, which worked with local private equity and firms to facilitate a water facility project in the form of BOT (Build-Operate-Transfer). Rules were set to require local businesses to construct the water facility in cooperation with local farmers to form effective cooperative management to sustain the facility (McWong 2016).

The ecology system of China not only plays an important role in the lives of its citizens, but also has a great effect on recent global weather changes. From the ecology classification prospective, China has forests, wetlands, grass fields, deserts, and many diversified natural systems as well as manmade farms and cities. The impairment of the above ecologies expose the problems and hazards for people and animals that live on the land. Weak ecological areas and disrupted ecosystems are scattered around China, and they must be repaired before the situation gets worse and costs become a heavier burden.

A reasonable water price is regarded as an important lever for any economy, as it can help prevent pollution, save water, accumulate funds, and offer public services and maintenance. Accordingly, how to set the suitable water price for long-term water system development would be the urgent issue in China's water sector reform (Zhong and Mol 2010). Current Chinese law on water resource protection has many flaws, which include vague definitions of water resource rights, ambiguous and contradictory laws, and latency in formalizing laws that affect the water resource management system. The incomplete water rights system results in a lack of legislative support for water rights trading, which is not suitable for adapting into a market economy. Ambiguous legislation is the biggest problem in the legal system, as the laws are incomplete or do not serve their purpose. With the incompleteness of water resource law, fines (punishment) handed out due to water pollution are relatively low and sometimes do not comply with local laws, which are tailor-made for the local industries.

In conclusion, water congestion efficiency is often the result of too much input or inefficient output. The current mindset of water conservation in China is very weak due to the whole country's pursuit of rapid economic growth. It is possible to improve the vast water efficiency problem by applying new technologies and revising regional master planning, but any effective implementation of technology requires integrated master plans, structured policies, and most importantly people's support. Hence, the most important task is to educate people to have the correct water conservation mindset and a consistent attitude towards executing projects. Physical problems can be resolved through technology and management, but only when the ideology of water resource sustainability is common to everyone can the root of water congestion inefficiency be eliminated.

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