

A New Indicator to Evaluate by Sector Water Use Efficiency and Its Application

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Abstract—The aim of this study is to find a reasonable indicator to evaluate by sector water use efficiency (WUE). Based on a water resource input-occupancy-output model, a new indicator (total water use coefficient) that considered indirect demand effects and occupancy was provided. Use this indicator and the commonly used indicator (direct water use coefficient), WUE by 19 sectors in Beijing in 2002 and 2007 was evaluated. Results showed that to each sector, its total water use coefficient is bigger than its direct water use coefficient. The order of WUE for 19 sectors was different with the two indicators. This indicated that, when one evaluated WUE, the indirect water consumption couldn't be ignored. The new indicator (total water use coefficient) was more reasonable.

Keywords—water use efficiency; indicator; indirect water consumption; input-output analysis; Beijing

I. INTRODUCTION

The efficient use of resources—water, nutrients, energy, chemicals and labour—has always been a major determinant of the profitability of production systems. A single WUE index can be useful for comparing alternative production systems or for monitoring change in practice over time. In many countries like Australian and China, increasing the efficiency of water use has been a major goal of research and development programs (e.g. Condon *et al.*, 2004; Rodriguez and Sadras, 2007; Y.B.Fan *et al.*, 2014; Y.H. Huang *et al.*, 2012).

The water use efficiency of an economic system or one industry is, by definition, the ratio of the amount of output of the economic system or the industry to the input or flux of water used in its production. As is well known, however, (e.g. Perry *et al.*, 2009) there is no consensus as to which water flux or which output should be used to compute this ratio. Except to these problems, the indirect water use is often been ignored in the WUE calculation. It is obvious that water is used directly and indirectly in the production process. For example, in the grain production, electricity is one kind of input, to the production of this amount of electricity, water is also needed indirectly, and this part of water is not considered in the WUE calculation usually.

This paper therefore has two objectives. First, a new index is proposed, based around a collection of related water use efficiency indices. This 'new index' is generic in nature and has a range of possible applications. The second aim is

to use an example to demonstrate the difference between the new index and the common index and indicated the usefulness of the new index.

The paper is organized as follows. Section 2 describes framework of water resource Input-Occupancy-Output (IOO) table for Beijing, China. Section 3 presents water use efficiency index and applies it to Beijing. Section 4 presents the calculation results. Section 5 makes conclusions.

II. INDICATORS TO EVALUATE WATER USE EFFICIENCY

The framework of water resource IOO table was shown in Table I. Regional economy is divided into 19 sectors (See Appendix 1) for data limitation. Water-intensive sectors 1-9 were separated specially from other sectors. Based on water resource IOO table, two kinds of indicators to evaluate water use efficiency were established. An indicator of direct water use coefficient for each sector (Iwd_j) is defined as this,

$$Iwd_j = wd_j / x_j \quad (1)$$

where wd_j is the amount of water consumed directly by sector j , and x_j is the output of sector j in monetary terms. Iwd_j is commonly used in many researches.

TABLE I. THE FRAMEWORK OF WATER RESOURCE INPUT-OCCUPANCY-OUTPUT (IOO) TABLE

			Intermediate Demands	Final Demands	Total Output
			1,2,……, n	1,2,……, t	
Input	Intermedi-ate Input	1,2,……, n	X_{ij}	Y_{ij}	X_i
	Primary Input	1,2,……, s	V_j		
	Total Input		X_j		
Occupancy	Fresh Water		wd_j		
	Fixed Assets		D_j		
	Labor Force		L_j		

In addition to this physical water consumption in equation (1), other goods and services are required by the production processes of sector j . Consequently, in order to

produce the inputs generated by other sectors, another requirement of water is also necessary. For sector j , this is the indirect water consumption. Direct consumption plus indirect consumption together amount to the total water consumption. By analogy with the input-output model, the calculation of total water consumption depends on the direct water consumption and the intersectoral dependence.

The solution for the total water use coefficient Iwt is available as follows,

$$Iwt = Iwd * (I - A)^{-1} \quad (2)$$

where $(I-A)^{-1}$ is known as the Leontief inverse matrix, which represents the total production that every sector must generate to satisfy the final demand of the economy (Leontief, 1966).

Based on IOO techniques (Chen, 1990), the formula to calculate total water use coefficients was brought forward as follows.

$$I\bar{w}t = Iwd(I - A - \hat{\gamma}D)^{-1} \quad (3)$$

$I\bar{w}t$ denotes total water use coefficients considering occupancy. D represents direct occupancy coefficients matrix of fixed assets. γ is a diagonal matrix of fixed assets depreciation rate.

The input-output analysis also accounts for the “drag” effect, which has this name because it indicates how evolution of a given sector can exert a drag upon the total economic production. Following Vela'zquez (2005), this drag effect can be measured by dividing the total water use coefficient by the direct water use coefficient.

$$md_j = I\bar{w}t_j / Iwd_j \quad (4)$$

where md_j is the water consumption multiplier that expresses the total quantity of water consumed by the whole

economy per unit of water used directly to satisfy the demand of sector j .

After the multiplier md_j has been defined, it is easy to obtain a multiplier of indirect water consumption (mnd_j), simply by subtracting one from the md_j .

$$mnd_j = md_j - 1 \quad (5)$$

In this way, the indicator yields an estimation of the quantity of water used indirectly by sector j for each unit of water that is consumed directly.

III. APPLICATION

Beijing, China's capital, has been constantly coming up short in terms of water. To use and manage the available water resources effectively, it is necessary to know water use efficiency of each sector in advance. For the data source, the 2002 and 2007 input-output tables of Beijing were published by Beijing Statistics Bureau. The direct water use data for 4 main sectors (agriculture, industry, domestic and environment) sourced from Beijing Water Bulletin 2002 and 2007. The detailed direct water use data by industry sectors were deduced from Duan *et al.* (2007) and Xu (2006) and Beijing Water Bulletin 2002 and 2007. The detailed direct water use data by tertiary sectors were deduced from Wang *et al.* (2008) and Beijing Water Bulletin 2002 and 2007. The employees and the fixed assets data was cited from Beijing Statistics Book 2003, 2008 and Beijing Economic Survey 2008.

With equations (1), (3) and (5), Iwd , $I\bar{w}t$ value and mnd value in 2002 and 2007 were calculated. Set 2002 as base year, the corresponding index was signed as $Iwd0$, $I\bar{w}t0$ and $mnd0$. And the index in 2007 was signed as $Iwd1$, $I\bar{w}t1$ and $mnd1$. Calculation results were listed in Table II. Table III gave the top 3 sector of WUE with the value of Iwd , $I\bar{w}t$ in 2007 and 2002.

TABLE II. THE WATER USE EFFICIENCY FOR 19 SECTORS OF BEIJING IN 2007 AND 2002

Sector Code	1	2	3	4	5	6	7	8	9	10
$Iwd1$ (m ³ /10000yuan)	455.46	3.96	19.59	8.40	3.76	12.52	19.21	2.75	0.62	17.08
$I\bar{w}t1$ (m ³ /10000yuan)	722.59	238.50	254.14	61.80	57.16	48.07	58.25	30.27	25.38	54.19
$mnd1$	0.59	59.28	11.97	6.36	14.19	2.84	2.03	10.00	39.72	2.17
$Iwd0$ (m ³ /10000yuan)	628.66	6.70	15.82	12.60	4.86	13.89	38.43	5.76	1.07	135.64
$I\bar{w}t0$ (m ³ /10000yuan)	939.11	188.74	197.86	97.36	89.61	79.07	121.77	66.98	46.24	178.18
$mnd0$	0.49	27.18	11.50	6.73	17.45	4.69	2.17	10.63	42.32	0.31

TABLE II. THE WATER USE EFFICIENCY FOR 19 SECTORS OF BEIJING IN 2007 AND 2002(CONT.)

Sector Code	11	12	13	14	15	16	17	18	19
Iwd1 (m ³ /10000yuan)	5.65	1.47	24.29	1.97	20.15	7.71	21.54	182.83	2.15
$I\bar{w}t1$ (m ³ /10000yuan)	40.52	19.27	116.37	35.09	50.68	44.18	45.79	245.74	27.69
mnd1	6.17	12.07	3.79	16.83	1.52	4.73	1.13	0.34	11.88
Iwd0 (m ³ /10000yuan)	30.84	2.67	52.45	4.90	42.96	35.10	48.80	124.79	4.22
$I\bar{w}t0$ (m ³ /10000yuan)	107.42	29.34	143.60	52.45	87.95	90.02	95.07	175.17	52.79
mnd0	2.48	9.99	1.74	9.70	1.05	1.56	0.95	0.40	11.50

Table II showed that to each sector, its total water use coefficient is bigger than its direct water use efficiency for the total water use efficiency includes the indirect water use. The bigger the value of *mnd*, the more indirect water was consumed by the sector. In 2002, sector 9, sector 2, sector 5 had the top 3 value of *mnd*. In 2007, sector 2, sector 9 and sector 14 were the top 3 sector of the *mnd* value. To the direct water use coefficient, except sector 18 (Management of Water Conservancy, Environment and Public Facilities), all the other sectors' *Iwd1* value is smaller than their *Iwd0* value. 15 sectors' changed rate is belonging to range [-80%,-40%]. During 2002-2007, Chinese government paid much more attention to the development of water conservancy, ecological protection and environmental management, much more water was distributed to Management of Water Conservancy, Ecological protection and environmental management industry, Public Facilities Management than before. These sectors were subsectors of Sector 18. So the *Iwd1* value of Sector 18 was increased.

To the total water use coefficient, the $I\bar{w}t1$ value of sector 2, sector 3 was increased from 2002, not as like their *Iwd1* value decreased from 2002. Thirteen sectors' $I\bar{w}t1$ value is smaller than their $I\bar{w}t0$ value. Sector 8 had the biggest negative changed degree -58.2%, the following was sector 10, the change rate was -58.15%. If the total water use coefficient was choose as the index to evaluate the WUE of Beijing, sector 12 had the biggest water use efficiency in 2002 and 2007. If with the direct water use efficiency, sector 9 was the top one. The main reason was the value of *mnd* indicated that sector 9 consumed more water indirectly than sector 12. The order for WUE of other sector was also different with the two indexes (See Table III).

TABLE III. THE TOP 3 SECTORS OF WUE WITH THE VALUE OF *Iwd*, $I\bar{w}t$ IN 2007 AND 2002

	1	2	3
Iwd1	sector 9(0.62)	sector 12(1.47)	sector 14(1.97)
$I\bar{w}t1$	sector 12(19.27)	sector 9(25.38)	sector 19(27.69)
Iwd0	sector 9(1.07)	sector 12(2.67)	sector 19(4.22)
$I\bar{w}t0$	sector 12(29.34)	sector 9(46.24)	sector 14(52.45)

IV. CONCLUSIONS

This paper set up a new water use efficiency index which includes indirect demand effects and considers occupancy. Applied the index to Beijing, it's found that the new index was a more rational indicator to reflect a sector's water consumption status. To sector 2 and sector 3, though their direct water use coefficient was decreased, their total water use coefficient increased during 2002-2007.

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REFERENCES

- [1] A.D. Moore, M.J. Robertson, & R. Routley (2011). Evaluation of the water use efficiency of alternative farm practices at a range of spatial and temporal scales: A conceptual framework and a modelling approach. *Agricultural Systems*, pp.162-174.
- [2] A.G. Condon, R.A. Richards, G.J. Rebetzke, & G.D. Farquhar (2004). Breeding for high water-use efficiency, *Journal of Experimental Botany*, 55: 2447-2460.
- [3] B.A.M. Bouman (2007). A conceptual framework for the improvement of crop water productivity at different spatial scales, *Agricultural Systems*, 93: 43-60.
- [4] C. Perry, P. Steduto, R.G. Allen, & C.M. Burt (2009). Increasing productivity in irrigated agriculture: agronomic constraints and hydrological realities, *Agricultural Water Management*, 96: 1517-1524.
- [5] D. Molden, H. Murray-Rust, R. Sakthivadivel, & I. Makin(2003). A water-productivity framework for understanding and action, J.W. Kijne, R. Barker, D. Molden (Eds.), *Water Productivity in Agriculture: Limits and Opportunities for Improvements*, CABI Publishing, Wallingford, UK, pp. 1-18.
- [6] D. Rodriguez, & V.O. Sadras(2007). The limit to wheat water-use efficiency in eastern Australia I. Gradients in the radiation environment and atmospheric demand, *Australian Journal of Agricultural Research*, 58: 287-302.
- [7] D.J. Reuter, A.D. Moore, P.K. Khanna, D. Tennant, G.D. McLean, R.J. French, & F.J. Hingston(1996). Indicators of farm productivity and financial performance, J. Walker, D.J. Reuter (Eds.), *Indicators of Catchment Health: A Technical Perspective*, CSIRO Publishing, Melbourne, pp. 47-66.
- [8] G.D. Farquhar, J.R. Ehleringer, & K.T. Hubick(1989). Carbon isotope discrimination and photosynthesis. *Annual Review of Plant Physiology and Plant Molecular Biology*, 40: 503-537.

- [9] Peden, D., Tadesse, G., & Misra, A.(2007). Water and livestock for human development. In: Molden, D. (Ed.), *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*. International Water Management Institute, Colombo, Sri Lanka and Earthscan, London, pp. 485-514.
- [10] R.J. French, & J.E. Schultz(1984). Water-use efficiency of wheat in a Mediterranean-type environment.1. The relation between yield, water-use and climate. *Australian Journal of Agricultural Research*, 6 : 743-764.
- [11] Y. Wang, Y.Sh. Chen and Y.L. Jiang (2008).Characteristic Analyze of Public Domestic Water of Beijing City. *Water & Waste Water Engineering*, 34:138-143 (In Chinese).
- [12] Y.B. Fan, CH.G. Wang, & ZH.B. Nan(2014). Comparative evaluation of crop water use efficiency, economic analysis and net household profit simulation in arid Northwest China, *Agricultural Water Management*, 146:335-345
- [13] Y.H. Huang, D. Jiang, D.F. Zhuang, J.H. Wang, H.J. Yang, & H.Y. Ren(2012). Evaluation of relative water use efficiency (RWUE) at a regional scale: a case study of Tuhai-Majia Basin, China, *Water Science & Technology*,66 : 927-933.
- [14] Zh.G. Duan, Y. P. Hou ,& Q. W. Wang (2007), Beijing Industrial Sectors Water Consumption Analysis, *Industrial Technology & Economy*, 26:47-49 (In Chinese).
- [15] Zh.J. Xu(2006). The Study on Water Consumption Trend and Strategies on Industry& Main Industries in Beijing, *Beijing Institute of Civil Engineering and Architecture Master Degree Thesis*(In Chinese).

APPENDIX 1. SECTOR CLASSIFICATION OF THE WATER RESOURCE (IOO) TABLES OF BEIJING, CHINA IN 2002 AND 2007

Sector Code	Sector Name	Sector Code	Sector Name
1	Agriculture, Forestry, Animal Husbandry & Fishery	11	Other industries
2	Manufacture of foods	12	Commercial Industry
3	Manufacture of Beverage	13	Hotels and Catering Services
4	Manufacture of Raw Chemical Materials and Chemical Products	14	Scientific Research and Integrated Technical Service
5	Manufacture of Medicines	15	Education
6	Manufacture of Non-metallic Mineral Products	16	Health, Social Security and Social Welfare
7	Smelting and pressing of Ferrous Metals	17	Public Management and Social Organization
8	Manufacture of Transport Equipment	18	Management of Water Conservancy, Environment and Public Facilities
9	Manufacture of Communication Equipment, Computers and other Electronic Equipment	19	Construction and other tertiary industries
10	Production and supply of Electric Power and Heat Power		