A regional inventory of water demand and water pollutant discharge in the Yangtze River and China as a whole based on an inter-regional input-output analysis model

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ABSTRACT: In this study, a regional inventory model based on an inter-regional input-output analysis model was developed that described water demand and water pollutant discharge, including the effects of hidden flows. This model is based on the regional model for the city of Chongqing (Okadera et al., 2006), and then applied to the Yangtze River and China, which is currently suffering from water shortages caused by rapid economic growth. This study has analyzed the structure of water demand and water discharge in the Yangtze River and China with the same indices (e.g. water consumption, virtual water and chemical oxygen demand). The results calculated using the model generated here indicate that China's economy depends heavily on the Middle of the Yangtze River to meet its water demands and handle its water pollutant discharge. The calculated results demonstrate that water demand is impacted by hidden flows in the Middle Yangtze region that occur as a result of exports to foreign countries, North and South China and the Lower Yangtze region. However, it is considered that this structure is efficient for China given the efficiency of water use. On the other hand, it is considered that the existing regional structure of production and consumption increases the discharge of water pollutants in the Middle Yangtze region.

KEYWORDS. Water demand, water pollutant discharge, inter-regional inventory, interindustry analysis model, input-output table

1 Introduction

China is undergoing a water shortage crisis caused by rapid economic growth, which can increase both water consumption and water pollutant discharge; and analyses are required that allow for both sustainable water use and economic activity. An emission inventory is a useful method of determining how much water is required and the level of pollutants that are discharged by various socioeconomic activities. Emission inventories can be based on statistics, an input-output table or a general equilibrium model. In this study, we developed an emission inventory based on an input-output table. Development of an emission inventory based on an interindustry table (Leontief, 1970; Duchin, 1985; Duchin, 1992) is commonly used to calculate environmental loads such as

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greenhouse gases and air toxicity (Gay and Proops, 1993; Nansai et al., 2003; Suh et al, 2004), energy consumption (Williams, 2004), waste materials (Huang et al., 1994; Nakamura, 1999), water demand and water pollutants (Harris and Rea, 1972; Ni et al., 2001; Guan and Hubacek, 2007) and ecological footprints (Lenzen and Murray, 2001; Ferng 2001), while taking into account national or regional socioeconomic activities. A prominent feature of this approach is that it can estimate direct environmental loads from industrial sectors, as well as indirect loads induced by the final demand for goods and services. Therefore, this type of model can be used to evaluate domestic environmental loads as well as those induced in external areas through hidden flows. Accordingly, this type of model is suitable for China, which has a high volume of international trade and foreign investment.

At the same time, it is necessary to think about regional characteristics in China, because economic standards and growth differ regionally in China, and it is considered that domestic trade among regions, as well as foreign trade, promotes economic growth in China. In addition, water resource distribution varies regionally, and water is generally more abundant in southern than in northern China. Therefore, though most previous inventories based on interindustry analysis models used national or regional models, this study develops a regional inventory of water demand and water pollutant discharge based on inter-regional input-output analysis models, and applies it to the Yangtze River and to China as a whole to lead to an understanding of the structure of water consumption and water pollutants discharged by economic activities.

2 Materials and Methods

2.1 A framework on a regional inventory of water demand and water pollutant discharge based on an inter-regional input-output analysis model.

When we think about flows of water demand and water pollutant discharge in the case of trading goods and services between two regions (Figure), the flows of goods and services in Region 1 consist of three types of inputs: internal resource loading, imports from foreign countries, and from Region 2, and three kinds of outputs: internal consumption, exports to Region2, and exports abroad. With the flows of goods and services, water flows can be drawn as using withdrawal from water resources in Region 1 as one of the internal resource loadings and discharging water pollutants as wastewater to water resources. As an aspect of the production of goods and services, withdrawal is defined by production scales and productivities. On the other hand, from the viewpoint of consumption of goods and services, withdrawal in Region 1 is determined by the places and amounts of the final consumption of goods and services, and water resources in Region 1 are affected by consumers in Region 2 and foreign countries. At the same time, withdrawals in Region 2 and foreign countries are influenced by the consumption of imported goods and services from Region 1. The same holds for water pollutant discharge, and it is important to understand quantitatively the dependencies of internal water resources used in the production and consumption of goods and services within and between regions on water demand and water pollutant discharge.

Thus we draft an inventory shown as Table 1. Table 1 consists of three main parts. First is the inter-regional input-output table which has intermediate demand, final demand, export and import of goods and services and value added by region. $\mathbf{x^{RS}}$ denotes a matrix of intermediate input from region R to region S that consists of entries x_{ij}^{RS}, which are the intermediate input from sector i in region R to sector j in region S, $\mathbf{Fd^{R}}$ is the vector of final demand of region R, $\mathbf{E^R}$ is the vector of goods and services exported from region R to foreign countries, $\mathbf{M^R}$ is the vector of goods and services imported to region R from foreign countries, $\mathbf{V^R}$ is the vector of value added in region R and $\mathbf{X^R}$ is the vector of total output or input in region R. The second part is a regional inventory of water demand where $\mathbf{WD^R}$ is water demand for the production of goods and services in region R, $\mathbf{WR^{RS}}$ is the matrix of regional withdrawal from water resources in region R for the production of goods and services exported to region S, $\mathbf{WR_E{}^R}$ is the matrix of regional withdrawal from water resource in region R for the production of goods and services exported to foreign countries and $\mathbf{WR_M{}^R}$ is the matrix of withdrawal from water resources in foreign countries caused by imports to region R. The third is a regional inventory of water pollutant discharge where $\mathbf{WP^R}$ is the water pollutant emission from the production of goods and services in region R, $\mathbf{WP^{RS}}$ is the matrix of regional water pollutant emissions in region R from the production of goods and services exported to region S, $\mathbf{WP_E{}^R}$ is the matrix of regional water pollutant emissions in region R from the production of goods and services exported to foreign countries, and $\mathbf{WR_M{}^R}$ is the matrix of water pollutant emissions in foreign countries caused by imports to region R.

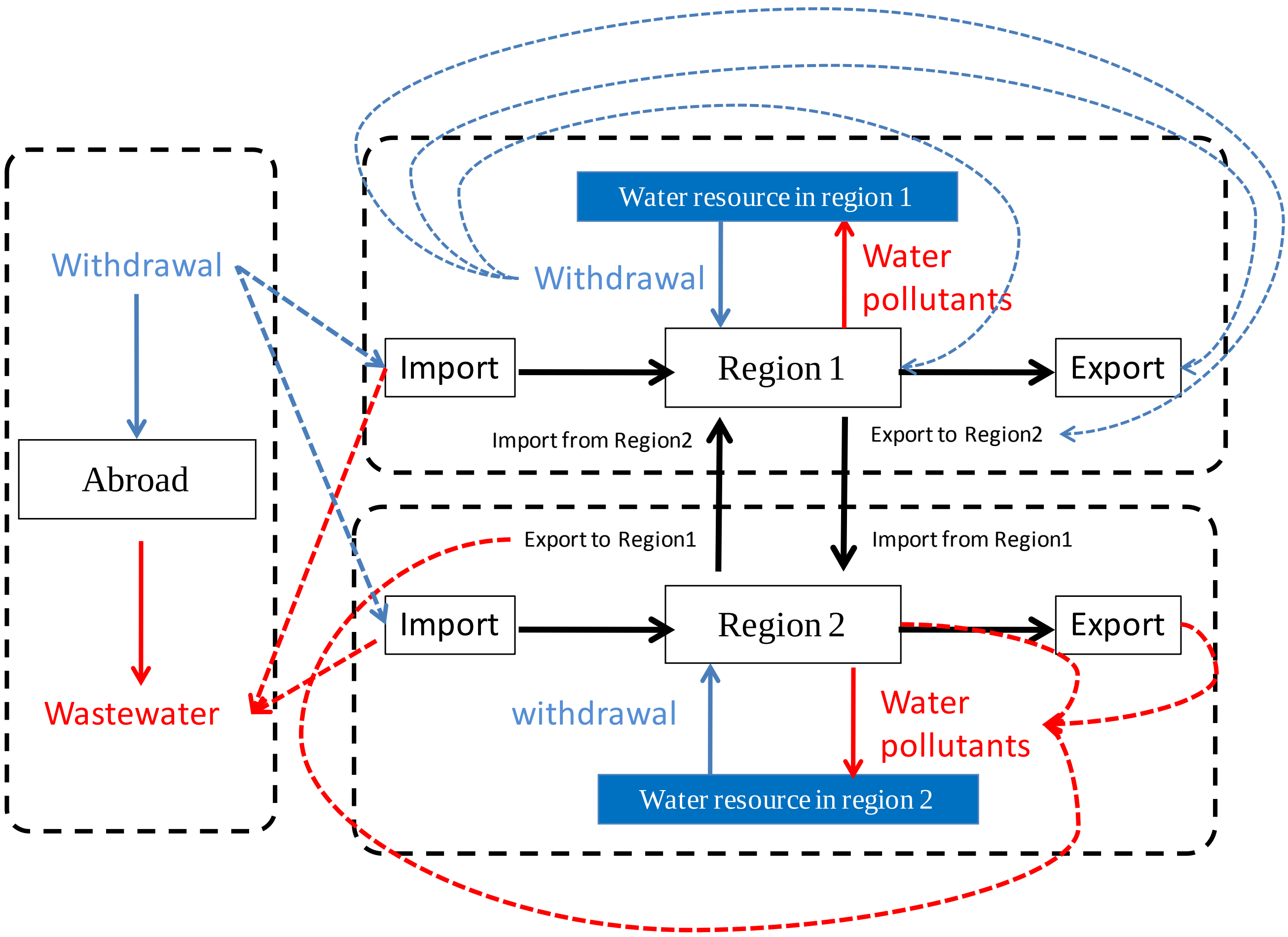

Figure. Diagram of water withdrawal and water pollutant flow between two regions

Table 1 Regional inventory of water demand and water pollutants based on the interregional input-output table

		Intermediate Demand		Final demand	Export	Import	Total output
		Region R	Region S				
Intermediate Input	Region R	$\mathbf{x^{RR}}$	$\mathbf{x^{RS}}$	$\mathbf{Fd^{R}}$	$\mathbf{E^{R}}$	$\mathbf{-M^{R}}$	$\mathbf{X^{R}}$
	Region S	$\mathbf{x^{SR}}$	$\mathbf{x^{SS}}$	$\mathbf{Fd^{S}}$	$\mathbf{E^{S}}$	$\mathbf{-M^{S}}$	$\mathbf{X^{S}}$
Value added		$\mathbf{V^{R}}$	$\mathbf{V^{S}}$				
Total input		$\mathbf{X^{R}}$	$\mathbf{X^{S}}$				
Water demand	Region R	$\mathbf{WR^{RR}}$	$\mathbf{WR^{RS}}$		$\mathbf{WR_E{}^{R}}$	$\mathbf{WR_M{}^{R}}$	$\mathbf{WD^{R}}$
	Region S	$\mathbf{WR^{SR}}$	$\mathbf{WR^{SS}}$		$\mathbf{WR_E{}^{S}}$	$\mathbf{WR_M{}^{S}}$	$\mathbf{WD^{S}}$
Water pollutants	Region R	$\mathbf{WP^{RR}}$	$\mathbf{WP^{RS}}$		$\mathbf{WP_E{}^{R}}$	$\mathbf{WP_M{}^{R}}$	$\mathbf{WP^{R}}$
	Region S	$\mathbf{WP^{SR}}$	$\mathbf{WP^{RR}}$		$\mathbf{WP_E{}^{S}}$	$\mathbf{WP_M{}^{S}}$	$\mathbf{WP^{S}}$

2.2 Calculation of water demand

Based on Table 1, equation (1) is given as

$$\mathbf{X = AX+Fd+E-M} \quad (1)$$

where $\mathbf{X}$ is the gross output column vector, $\mathbf{A}$ is the input coefficient matrix, which is the input from sector i in region R needed to increase output in sector j in region R by one monetary unit, $\mathbf{Fd}$ is the regional final demand column vector, $\mathbf{E}$ is the export column vector and $\mathbf{M}$ is the import column vector.

Equation (1) is solved as

$$\mathbf{X = (I-A)^{-1}(Fd+E-M)} \quad (2)$$

Water demand can be calculated by multiplying the matrix of direct water requirement coefficients by the gross output. Thus equation (3) is solved by equation (2).

$$\mathbf{WD = D\,(I-A)^{-1}(Fd+E-M)} \quad (3)$$

where $\mathbf{WD}$ is the water demand matrix and $\mathbf{D}$ is the direct water requirement coefficients matrix. Equation(3) consists of three terms, the first term is defined as the water requirement for the production of goods and services for domestic final demand, the second is water requirement for exporting goods and services, and the third is the virtual water requirement (Oki, 2004) for importing goods and services. Therefore, we can describe water demand for export ($\mathbf{WR_E{}^{R}}$) and import ($\mathbf{WR_M{}^{R}}$) in Table-1 by equations (4) and (5)

$$\mathbf{WR_E{}^{R} = D(I-A)^{-1}E} \quad (4)$$

$$\mathbf{WR_M{}^{R} = D(I-A)^{-1}M} \quad (5)$$

In addition, the water requirement for the production of goods and services for domestic final demand is solved by equation (3) as equation (6).

$$\mathbf{D\,(I-A)^{-1}Fd} \equiv \begin{pmatrix} \mathbf{D^{R}} & \mathbf{0} \\ \mathbf{0} & \mathbf{D^{S}} \end{pmatrix} \begin{pmatrix} \mathbf{B^{RR}} & \mathbf{B^{RS}} \\ \mathbf{B^{SR}} & \mathbf{B^{SS}} \end{pmatrix} \begin{pmatrix} \mathbf{Fd^{R}} & \mathbf{0} \\ \mathbf{0} & \mathbf{Fd^{S}} \end{pmatrix} \quad (6)$$

where $\mathbf{D^{R}}$ is the matrix of direct water requirement coefficients in region R, $\mathbf{B^{RS}}$ denotes the Leontief inverse matrix consisting of the output in region R that is necessary for one monetary unit of final demand in region S and $\mathbf{Fd^{R}}$ is regional final demand for goods and services in region R. Equation (6) can give two types of regional water demand induced by the final demand for goods and services within or outside of a region

$$\mathbf{WR^{RR}} = \mathbf{D^{R}B^{RR}Fd^{R}} \quad (7)$$

$$\mathbf{WR^{RS}} = \mathbf{D^{R}B^{RS}Fd^{S}} \quad (8)$$

where $\mathbf{WR^{RS}}$ is the matrix of regional withdrawal from water resource in region R for the production of goods and services exported to region S.

2.3 Calculation of water pollutant discharge

The water pollutant discharge is calculated by multiplying the matrix of water pollutant emission factor by the gross output. The water pollutant discharge factor is fixed by water demand requirement coefficients, wastewater emission factor and water pollutant concentration (Okadera et al., 2006). Thus, items of water pollutant discharge in Table-1 are solved as equations (9)-(13)

$$\mathbf{WP = DP(I\text{-}A)^{-1}(Fd+E\text{-}M)} \quad (9)$$

$$\mathbf{WP_E^{R} = DP(I\text{-}A)^{-1}E} \quad (10)$$

$$\mathbf{WP_M^{R} = DP(I\text{-}A)^{-1}M} \quad (11)$$

$$\mathbf{WP^{RR}} = \mathbf{DP^{R}B^{RR}Fd^{R}} \quad (12)$$

$$\mathbf{WP^{RS}} = \mathbf{DP^{R}B^{RS}Fd^{S}} \quad (13)$$

where $\mathbf{WP_E^{R}}$ is the matrix of water pollutant discharge to produce goods and services exported from region R, $\mathbf{WP_M^{R}}$ is the matrix of virtual water pollutant discharge to produce goods and services imported to region R, **DP** is the direct water pollutant emission factor matrix, $\mathbf{DP^{R}}$ is the matrix of direct water pollutant emission factor in region R and $\mathbf{WP^{RS}}$ is the matrix of water pollutants indirectly discharged in region R in the production of goods and services exported to region S.

2.4 Classification and data

For this study, China was divided into the following five regions: the Upper Yangtze region (UYR), which includes Chongqing, Shonxi, Sichuan, Guizhou, Gansu, Yunnan and Qinhai; the Middle Yangtze region (MYR), which includes Jiangxi, Hubei, Hunan and Henan; the Lower Yangtze region (LYR), which includes Shanghai, Chiangsu, Zhejiang and Anhui; the South China region (SCR), which includes Fujian, Guangdong, Guangxi and Hainan; and the North China region (NCR), which includes the remainder of China. The regions were selected based on climate, hydrology, geography and economy and the regional classification provided in the Yangtze River Yearbook (1999). Hong Kong was not included in this study because of data inaccessibility. Each region was then further divided into 30 industrial sectors based on the characteristics of water use and discharge and the limitations of data accessibility. A database was generated using the approach of the previous study (Okadera et al., 2006). The values for each of these parameters in the five regions and 30 sectors were then estimated using an inter-regional input-output table for China in conjunction with an interregional input-output model that was generated using a previously described method (Okamoto et al., 2005).

3 Results & Discussion

3.1 Regional inventories of water demand and water pollutant discharge in Yangtze River and China

A regional inventory of water demand in the Yangtze River and the rest of China is shown as Table 2. Water demand (withdrawal) of the MYR is the largest in the Yangtze River region. However, the MYR has the lowest percentage (74%) of water requirement for the production of goods and services for internal final demand against withdrawal; it is clear that other regions and foreign countries depend indirectly on the water resources of MYR. 51% of the water requirements of other regions and foreign countries in the MYR is induced by other domestic regions, of which 38% is caused by the UYR and LYR. As above, the water resources of the MYR are important for the production of goods and services in all of China. In conclusion, it is efficient for LYR, SCR and NCR whereas it is not efficient for UYR; because water demands per capita of LYR (431m^3), SCR (552m^3) and NCR (383m^3) are higher than for the MYR (365m^3), and it is considered possible to utilize the water resources in China efficiently.

Table-2 Regional inventory of water demand in the Yangtze River and China (10^8 m^3 / year)

	Intermediate demand					Export	Import	Water demand	Water demand per capita (m^3)
	UYR	MYR	LYR	SCR	NCR				
UYR	515	11	19	16	24	48	24	596	230
MYR	32	698	62	48	76	102	16	943	365
LYR	16	24	686	33	70	170	175	853	431
SCR	23	23	57	751	52	312	306	959	552
NCR	33	46	77	43	1,181	220	165	1,428	383

Table 3 is a regional inventory of water pollutant discharges based on chemical oxygen demand (COD) in the Yangtze River. The MYR is the region with the largest amounts of COD discharge (50 million t/year) into the Yangtze River. 21% of it is induced by production of export goods and services. The MYR has the highest levels of indirect discharge COD (water pollutants) into the water environment from other regions and foreign countries. Fifty-nine percent of indirect COD discharges due to exporting in the MYR are caused by other domestic regions, of which 34% is caused by the UYR and LYR. As above, the MYR is depended on by other regions in Yangtze River and China as a whole in respect of water demand. However, per capita COD of the MYR is the highest value (195 kg) apart from the SCR, leading to the suggestion that the existing structure of production and consumption in the Yangtze River region and China as a whole increases COD discharges in the MYR, while per capita COD in the LYR, which has a high COD discharge dependency on the MYR, has a low value.

Table 3 A regional inventory of water pollutant discharge in Yangtze River (10^4t-COD)

	Intermediate demand					Export	Import	COD discharge	COD per capita (kg)
	UYR	MYR	LYR	SCR	NCR				
UYR	3,437	48	71	81	103	230	89	3,823	148
MYR	130	3,982	226	218	308	433	56	5,034	195
LYR	33	48	2,408	81	151	429	437	2,835	143

SCR	68	67	155	2,761	149	986	933	3,430	197
NCR	110	150	244	148	4,632	802	567	5,487	147

3.2 Limitations of this study

Our study focused on the Yangtze River and we developed a method for analyzing water demand and water pollutant discharges by region. However, the area classification that we used does not completely match the Yangtze River divisions because, unlike geographic data (e.g. polygon data and point data), the socioeconomic data we used is built on administrative units (e.g. regional input-output table, population, number of employees, water demand). We are currently developing a new method to address this issue (Okadera et al., 2008).

In addition, water demand and water pollutant discharge caused by importing goods and services from foreign countries are defined as virtual amounts, which are the water requirement and water pollutant discharge. Because of data accessibility problems, these are calculated under the assumption that imported goods and services are produced by domestic regions in the Yangtze River area and China as a whole, and that they are not the water taken and water pollutants actually discharged in foreign countries. To address this lack of data, it is essential to build a global physical and social system to monitor water demand and water pollutant discharges from economic subjects as well as to collect global trading data. Furthermore, the model should be improved as based on a noncompetitive import type inter-regional input-output analysis model.

4 Conclusion

This study has developed regional inventories of water demand and water pollutant discharge based on an interregional input-output table and analyzed the structure of water demand and COD discharges in the Yangtze River region and the whole of China. As a result, it became evident that the existing structure, which depends on the water resources of the MYR, is appropriate from the aspect of water-use efficiency, although it promotes the discharge of water pollutants in the MYR. Therefore, it is considered that it is important to implement water pollutant treatment or new technologies which are productive and decrease water pollutants in the MYR for future water resource management.

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