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Article

Cross-Sectoral Analysis of Water Usage in Thailand Using Input–Output Model

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Abstract. Thailand currently ranks third among the most water-intensive countries in the world. The percentage shares of water demand in the country's agriculture, manufacturing, and service sectors, which are major economic sectors, are 75%, 3%, and 5%, respectively. With the continuous growth of the economy, the demand for water is steadily rising, while the expansion of water supply remains constrained by several factors and the water supply is also affected by climate change. This study uses the input–output model to examine the relationship between water usage and the economic system in Thailand in 2010. The constructed input–output model is the integration of the Leontief inverse matrix, the matrix of water usage, and the details of the gross domestic product (GDP). The model indicates the linkage between GDP expansion and water demand in both direct and indirect usage. The computation result obtained from the model indicates that the agricultural sector is the major water user, with its ratio of direct water use being the highest. The manufacturing sector records the highest ratio of indirect water use, which is influenced by its supply chain comprising the agriculture and service sectors. This model and its results may serve as the main foundation for the design of economic and environmental policies oriented toward optimizing water demand and supply. The model can also be extended and enriched with detailed mechanisms of economic behavior to allow further complex analyzes such as water pricing policies.

Keywords: Input–output model, water usage, economic system, gross domestic product, direct and indirect water usage.

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1. Introduction

The relationship between the environment and the economy, especially the linking of productive processes in the economic system and the consumption of natural resources, is important for socio-economic development in every country. Production processes mainly use natural resources such as water, gas, and minerals, which are generally limited according to the economic principle. Existing research only focuses on water usage for supporting potential development. The current work examines the inter-sectoral relationship between economic structure and water usage in Thailand because it is the second largest economy in Southeast Asia [1] to establish an open, export-oriented economy. Similar to other countries in Southeast Asia, Thailand faces major challenges with regard to the variability of water resources and climate change. Water demand in the country's main economic sectors, such as services, manufacturing, and agriculture, continues to increase, thereby influencing the country's fragile water infrastructure and resources. Currently, the infrastructure for waste water and sanitation in Thailand is underdeveloped. The discharge of industrial waste in rivers is excessive, causing water pollution and health problems. In recent years, the country has suffered from droughts and floods, which are events that highlight the need for a comprehensive water management plan. Therefore, policymakers must utilize guidelines that are based on the assessed water needs of every economic sector. In this paper, the direct and indirect water usage linked to the production of each sector and their impact on the availability of resources are examined.

The objective of this study demonstrates two results. First, we propose a methodology to analyze the structural relationship between a production process and water usage. This methodology leads to the development of the input–output model (I-O model) of sectoral water usage, which combines the extended Leontief I-O model with the Proops model [2]. The Proops model was developed for studying energy use. Second, we apply the methodology to analyze the case of Thailand. According to Velazquez [3], the I-O model enables the analysis of structural relationship between a production activity and its physical relationship with the environment. Thus, the present study enhances our understanding of the relationship between the economy and the environment and increases our awareness of sustainable water management. The description of water usage patterns and trends can aid in formulating sustainable water policies at the national level, including water pricing, water footprints and other measures.

1.1. Research Backgrounds

This research focuses on the relationship between economic systems and the demand for water [3]. The efforts toward integrating international environmental accounts with other organisms were spearheaded by the United Nation [4], collectively known as the "System of Integrated Environmental and Economic Accounts" (SEEA). Thereafter, a step in continual development led to the "National Accounting Matrix including Environmental Accounts" (NAMEA), which was developed by the Netherlands following its SEEA indication. The conception of the NAMEA system is based on the work of De Boo et al. [5] and De Haan et al. [6]. The origin of their work is the I-O approach of Leontief [7]. This matrix shows all the information in a compact format that ensures the consistency of combined accounts because the row sum must be equal to the column sum [8].

A number of studies use the environmentally extended I-O table, which was developed by Leontief in 1970. Most studies adopt a consumption perspective to energy consumption and environmental pollution. Forsund [9] used an extended I-O model to examine an analysis focused on atmospheric pollution. Wiedmann et al. [10] and Wiedmann [11] reviewed some recent research in terms of natural resource consumption. In 1998, Proops used the extended I-O framework to establish a number of indicators of direct and indirect energy consumption and later explored a comparative study of Germany and the United Kingdom that applied his indicators to atmospheric pollution. Subsequently, Hawdon et al. [12] demonstrated the complicated relationship between energy, environment, and economic welfare by using 10 sectors from the I-O model of the United Kingdom.

The first environmental I-O table in Spain was issued by the Environmental Agency of the Junta de Andalucía for the year 1990 [13]. The table included data, expressed in physical units, on both the environmental inputs used by the production sectors and the pollutants generated by those sectors. Similar tables were developed in Valencia by Almenar et al. [14]. The I-O model also was used on environmental issues in past research. Hubacek et al. [15] estimated the changes in land use in the Chinese context. Peters et al. [16] carried out an analysis of pollution in international trade. Liang et al. [17] performed an analysis of energy requirements and CO_2 emissions by using the Chinese I-O table.

The study on water usage using the I-O table points out that natural resources receive little attention from an economic point of view, especially within the I-O framework, although the first studies in the area date back to the 1950s. The main reason is due to the methodological difficulties that arose when the water consumption variables were introduced in the I-O model. Particularly, the assumption of proportionality among monetary and physical transactions was violated because of the considerable variation in water prices of the economic sectors. These difficulties were addressed by Lofting et al. [18], who introduced the water requirements in physical units as inputs in the I-O framework. Chen [19] used this framework to study the water demand and supply balance in Shanxi Province in China. On the basis of the table rooted in transcendental logarithmic production function and linear programming model, the authors were able to assess the economic value of water. Along with the I-O analysis results, they proposed a water-resource-saving economy for Shanxi Province. Lenzen et al. [20] analyzed water use in Australia and found that the predominantly urban population is responsible for the entire water consumption. One year later, Duarte et al. [21] used the I-O methodology to study the effect of Spanish water consumption on the hypothetical extraction framework. Okadera et al. [22] analyzed the water demand and pollution discharge in the Three Gorges Dam in China. In 2006, Velazquez studied the inter-sectoral water relationship in Andalusia [3]. In addition, Velazquez's methodology was adapted by Wang et al. [23] to analyze regional water consumption in Zhangye City. However, the matrix of inter-industry water relationship was derived in a slightly different manner. Another recent study is that of Yu et al. [24], who attempted to identify the key water consuming sectors in North and South UK by using the regional extended I-O methodology.

Although the methodologies used in all the above studies are similar, the availability of water accounting data should still be considered. In Velazquez [3], the Andalusia environmental I-O table enabled the quantification of the inter-sectoral relationship in terms of water consumption in cubic meters. Wang et al. [23] accessed the data on water-intensive agricultural use at the most detailed level, which is published annually by the Gansu Provincial Bureau of Water Resources. Moreover, Lenzen et al. [20] used the first published water accounts in 1993–1997 by the Australian Bureau of Statistics in their I-O analysis. These water accounts cover the water use and supply at the state and territory levels of self-extracted and main water, as well as the effluent reuse and regulated discharge of households and industries.

1.2. Water Situation in Thailand

Water is an essential component of natural and socio-economic systems. From an economic perspective, water plays an important role in the supply chains of almost all sectors, because this natural resource can become a constraint for economic growth and development through increased demand. In this study, we aim to review the water situation in Thailand and the relationship between sectors, especially in terms of water demand and supply. Thailand covers a land area of 513,115 km^2. It extends 1,500 km from north to south and 800 km from east to west. The golden axe shapes both the South China Sea and the Indian Ocean. Thailand is bordered by Malaysia in the south, the Union of Myanmar in the west and northwest, the Lao People's Democratic Republic to the northeast, and Cambodia to the southwest. As of 2016, the estimated population was at 66–67 million, with a growth rate of 0.35% [25]. In the same year, the urban population was approximately 15 million, with high density observed in the capital city and regional centres.

The country has a total agricultural area of about 265,200 km^2. More than 60% of the population is engaged in agriculture, yet agricultural production accounts for only about 10% of the GDP. As a result of the rapid economic development in the past decade, water demand continues to grow, and two of the four regions, namely, the Northeast and the Central Plain, experience frequent droughts. Flooding also occurs frequently due to deforestation. The budget for water resources development has been increasing, and it represents a large portion of the national budget for development. However, current environment constraints may slow down large projects for water resources development in the future. The agricultural sector remains the main user of available water and accounts for 75.1% of total water demand. The industrial sector accounts for 2.8%, the service sector accounts for 4.2%, and the remaining 17.9% represents ecological balance.

Thailand can be divided into four main geographical regions: the North, the Central Plains, the Northeast, and the South. The North is mainly mountainous, and it serves as the origin of four major rivers (Ping, Wang, Yom, and Nan rivers) that converge to become the Chao Phraya River, which is the lifeline of the Central Plain. The whole region lies at an elevation of above 200 m. The Northeast occupies one-third of the country's total land area and is the most populous region with the lowest income. The Northeast is a dry plateau at 100–200 m elevation. Large parts of this region regularly experience periods of floods alternating with periods of drought. Saline soils are also a major problem in this region. As a result, the productivity of the land is generally low. The water resources in Thailand can be divided into 25 river basins according to geographical characteristics. The average annual rainfall for the country is approximately 1,700 mm. The total annual rainfall of all river basins is about 800,000 million m³, 75% of which is lost through evaporation and evapotranspiration, and the remaining 25% (200,000 million m³) is released in streams, rivers, and reservoirs (Tables 1). Thus, the available water quantity is about 3,300 m³/capita/year [26].

Table 1. Surface water in Thailand.

Region	Catchment area (km^2)	Average annual rainfall (mm/year)	Amount of rainfall (million m^3)	Amount of runoff (million m^3)
Northern	169,640	1,280	217,140	65,140
Central	30,130	1,270	38,270	7,650
North-eastern	168,840	1,460	246,500	36,680
Eastern	34,280	2,140	73,360	22,000
Western	39,840	1,520	60,560	18,170
Southern	70,140	2,340	164,130	49,240
Total	512,870	-	799,960	198,880

1.3. Organization of The Study

This paper is organized in four sections. After the introduction, the I-O model of sectoral water usage is presented. Several indicators of sectoral water usage in Thailand are also established to analyze direct and indirect water usage of this resource by different sectors. The model is a matrix of inter-sectoral water relationships; this matrix, together with the afore mentioned indicators, allows us to define technical coefficients and distribution coefficients, which are expressed in terms of water. Then, we present the results and the subsequent analysis. Finally, the main conclusions drawn from the study are outlined.

2. Input–Output Model for Cross-Sectoral Analysis of Water Usage and The Matrix of Inter-Sectoral Water Relationships

In this part, we explain the I-O model of cross-sectoral water usage that is constructed for this study. The primary equations of the Leontief I-O table are used to determine the I-O model of production, which is then employed to develop the I-O model of water usage.

2.1. Traditional Leontief Input-Output Model of Production

This section explains the traditional I-O model used as the fundamental of analysis. The I-O table is developed from the observed data for a particular time period and a geographic region. In the case of Thailand, the I-O table is provided every five years by the Office of National Economic and Social Development Board (NESDB), The I-O table exhibits a mathematical structure through linear equations, as shown in a matrix representation in Table 2 [27].

Table 2. Traditional I-O Table.

Sectors	Consumer sector	Final demand	Total output
Agriculture Mining …	Z_{ij}	F_i	X_i
Value added	V_j	$V^F{}_j$	V_i
Imports	I_j	$I^F{}_j$	I_i
Total input	X_j	F_j	

The row represents the distribution of the producer output. The column represents the required input by a particular sector to produce its output. Table 2 shows additional columns as the final demand. The consumers of the economy are external to the sectors because domestic and foreign demand units are used as output and not as input. The additional row is the total value added to other non-industrial inputs to production; it consists of wages and salaries, operation surplus, taxes, and depreciation.

The I-O table's transaction balance among the sectors can be presented by the equations. The basic equation in the Leontief I-O model indicates that the production of an economy is generated from inter-sectoral relations and final demand. It can be written and summarized as follows:

$$x_i = \sum_{j=1}^{j=n} x_{ij} + y_i \tag{1}$$

where x_{ij} represents the values of inter-sectoral relations from each sector i to sector j, and y_i represents the final demand of products in each sector. This equation can be rewritten to include the technical coefficient of production (a_{ij}), which is defined as the purchases made by sector j from sector i per total effective production unit of sector j. It also represents the direct input required by sector j.

$$a_{ij} = \frac{x_{ij}}{x_j} \tag{2}$$

$$x_i = \sum_{j=1}^{j=n} a_{ij} x_j + y_i \tag{3}$$

In the matrix notation and for the economy as a whole, the equation becomes

$$x_i = Ax_j + y_i \tag{4}$$

By solving variable x, we obtain the total production transferred to the final demand.

$$x_i = (I - A)^{-1} y_i \tag{5}$$

where $(I - A)^{-1}$ is known as the Leontief inverse matrix or total requirement matrix representing the total production that every sector must produce to satisfy the final demand of the economy. This expression should be analyzed because it is the primary component of the I-O model of water usage. The production of sector i may be formulated as follows:

$$x_i = \alpha_{i1} y_1 + \alpha_{i2} y_2 + \ldots + \alpha_{in} y_n = \sum_{j=1}^{j=n} \alpha_{ij} y_j \tag{6}$$

where α_{ij} is the generic element in the matrix $(I - A)^{-1}$. If the demand of sector j increases in one unit, it increases in the production generated by sector i. Moreover, the coefficients are the amount by which sector i must change its production level to satisfy an increase of one unit in the final demand from sector j. Hence, the column sums of the Leontief inverse matrix express the direct and indirect requirements of a sector to meet its final demand [3]. Manresa et al. [28] pointed out that if the calculation is analyzed by substituting the production vector with the expression in the Leontief I-O model, then the matrix will simply show the specific direct requirement of productive sectors because the results from the substitution of the matrix $(I - A)^{-1}$ demonstrate the total requirement of the sectors, which comprise direct and indirect requirements.

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2.2. Input–Output Model of Water Usage

Before explaining the I-O model of water usage, it is necessary to set the definition of direct and indirect water usage in this study. Direct water usage is the water used directly by the individuals and indirect water usage is the summation of the water used of all the products consumed. On the basis of the explanation for the traditional Leontief I-O model of production, we develop the I-O model for water usage, which is considered from the water use of each sector. The traditional Leontief I-O model for production (Eq. (1)) can be expressed in terms of the variables of water usage. It can be written as follows:

$$w_{di} = \sum_{j=1}^{j=n} w_{ij} + w_{di}^{y} \tag{7}$$

Equation (7) shows that the amount of water directly consumed by sector i (w_{di}) depends on the inter-sectoral relationship found between a sector and the remaining sectors of the economy (w_{ij}) and the quantity of water consumed by sector i to meet its own usage (w^{y}_{di}). Consistent with the traditional Leontief I-O model of production, Eq. (8) can formulate a number of technical coefficients of water usage (q_{ij}), which are equivalent to the technical coefficients in the Leontief model (a_{ij}). The q_{ij} coefficients are defined as the quantity of water usage by sector j for providing inputs to sector i (w_{ij}) in relation to the total amount of water directly consumed by sector j (w_{dj}).

$$q_{ij} = \frac{w_{ij}}{w_{dj}} \tag{8}$$

If Eq. (8) is taken into account, then Eq. (7) becomes

$$w_{di} = \sum_{j=1}^{j=n} q_{ij} w_{dj} + w_{di}^{y} \tag{9}$$

In matrix notation, it is written as

$$w_{d} = Q w_{d} + w_{d}^{y} \tag{10}$$

where Q is the analogy with the standard Leontief model, which is a square n matrix of the technical coefficients of water usage with elements q_{ij}. We obtain the expression by solving the equation for determining the model of water usage.

$$w_{t}' = u' \left(I - Q\right)^{-1} \hat{w}_{d}^{y} \tag{11}$$

where $(I - Q)^{-1}$ is the Leontief inverse matrix in terms of water, u is a unit column vector, (^) places the vector on the diagonal of the matrix, and (′) indicates the transposition of the vector. As shown in Eq. (11), the matrix $(I - Q)^{-1}$ determines the change in water usage if the water demand changes in one unit, i.e., β_{ij}. The matrix shows the additional quantity of water that sector i will consume if the water demand of sector j increases by one unit. This section explains the production model when the Leontief inverse matrix is rewritten in terms of water $(I - Q)^{-1}$. The model can examine the direct and indirect water requirements. It reflects the total amount of water that any given sector consumes to satisfy an increase in demand. However, the matrix Q only reflects the direct water requirement. For this reason, a vector of total water usage (w_t) in Eq. (11) must substitute for the vector of direct water usage (w_d) in Eq. (10).

2.3. Indicators of Water Usage

The previous sections summarize the traditional I-O table and the I-O model of water usage. In this section, we take another step beyond the I-O model of sectoral water usage. As mentioned previously, this model is defined for total water usage. Nonetheless, distinguishing between direct and indirect water usage is interesting as these concepts can be introduced in the model. In this study, we formulate a matrix of inter-sectoral water relationship and analyze the importance of direct and indirect water usage. With consideration of the differences between direct and indirect water usage, we specify three indicators: direct water usage per unit produced, total water usage, and indirect water usage per unit produced. Once these indicators are specified, we introduce them in the matrix for water usage.

The first point is based on the data of sectoral water usage provided by related government agencies and calculated by Suttinon et al. [29]. The results of water calculation show the quantity of water consumed directly by each sector (w_d) of 180 sectors in cubic meters (m^3). We then consider the data on the effective production generated by each sector, as shown in Thailand's I-O table for year 2010 issued by the National Accounts Office [30]. Thus, we have the production vector (x) expressed in currency units. These data can be applied to calculate an indicator of total direct water usage per unit produced (w_d^*), which is defined as the amount of water consumed directly by each sector (w_d) per currency unit produced (x).

According to Velazquez [3], the value of w_d^* is defined by dividing the total amount directly consumed by each sector (w_{di}) with the total input to that sector (x_i).

$$w_{di}^* = \frac{w_{di}}{x_i} \tag{12}$$

In matrix notation, the equation may be represented as

$$w_d^{*\prime} = w_d^{\prime}\hat{x}^{-1} \tag{13}$$

where $\hat{x}$ denotes a diagonal matrix with the elements of x on the leading diagonal. Once the I-O model for water usage and the usage indicators have been defined, we can distinguish between direct and indirect water usage. Equation (13) can be rewritten into a total water usage multiplier simply by multiplying the direct water usage coefficient ($w_d^{*\prime}$) by the quantity produced by each sector.

$$w_d^{*\prime} = w_d^{\prime}\hat{x}^{-1} \tag{14}$$

According to Eq. (5), the production vector x maybe reformulated as the open Leontief model and used to obtain the total water usage (w) of the economy in terms of its own demand. Hence, Eq. (14) can be rewritten as

$$w = w_d^{*\prime}\left(I - A\right)^{-1} y \tag{15}$$

$$w^{*\prime} = w_d^{*\prime}\left(I - A\right)^{-1} \tag{16}$$

The equation is expressed for measuring total water usage. According to Manresa et al. [28], Eq. (15) denotes water content. At this point, the indicators of direct and total water usage have been defined. We now proceed to define an indicator of indirect water usage per unit produced (iwum). For this purpose, we return to the I-O model of water usage in Eq. (11). The formula serves as the basis for determining the elements β_{ij} of the Leontief inverse matrix for water usage. These elements indicate the additional quantity of water that sector i will consume if the demand for water of sector j increases by one unit. Thus, similar to the conventional Leontief model, the row sum in the matrix expresses the additional amount of water consumed by the economy as a whole when sector j increases its demand for water by one unit.

Velazquez [3] continued with her analysis of the adaptation of the Proops energy use model [2] by defining the expression $w_d^{*\prime}(I - A)^{-1}$ as an indicator of total water usage ($w^{*\prime}$). It is a row vector that determines the total amount of water that the economy will both directly and indirectly consume if water usage in any given sector increases by one unit. As indicated previously, total water usage comprises direct and indirect water usage. To capture indirect water usage, we must consider the "drag effect." The Leontief model accounts for this effect, which indicates how the evolution of a given sector can "drag" the total economic production. In terms of water usage, the "drag effect" is captured by the quotient between the earlier defined indicator of total water usage (w^*) and the indicator of total direct water usage (w_d^*), which is the water usage multiplier (wum).

$$wum_i = \left(I - A\right)^{-1} = \frac{w_i^*}{w_{di}^*} \tag{17}$$

The water usage multiplier can be interpreted in the same way as the column sum of the coefficients in the Leontief inverse matrix for water usage, because it shows the total quantity of water consumed by each sector that is multiplied if the final demand of a given sector increases. Therefore, wum gives an idea of the total quantity of water consumed per unit of water used directly to satisfy the demand of a given sector [23]. The indicators of iwum per currency unit produced may be obtained by simply subtracting the value of one from wum. It yields an estimate of indirect water usage by sector.

$$iwum_i = wum_i - 1 = \frac{w_i^*}{w_{di}^*} - 1 \tag{18}$$

2.4. Growth of Gross Domestic Product and Water Usage Relationships

The theory of the I-O model of water usage has been applied with the growth of GDP. This section studies the direct, total, and indirect water usage for generating GDPs in each sector. The total amount of water directly consumed by each sector (w_{di}) is determined by multiplying the total input to that sector (w_{di}^*) in Eq. (12) with the technical coefficient of production (a_{ij}). The same is applied for the calculation of total GDP, but it is changed to GDP ratio (v_{ij}). This matrix of relationships can be written and summarized as follows:

$$\text{Total water usage } (w_t) = w_{di}^* a_{ij} \tag{19}$$

$$\text{Total GDP} = v_{ij} a_{ij} \tag{20}$$

Based on the ratio of direct water usage w_{di}^*, the indirect water usage (w_{int}) is calculated as

$$w_{int} = (w_{di}^* a_{ij}) - w_{di}^* \tag{21}$$

These equations can be used to compute the ratios between water usage and GDP created, which is divided into three categories: direct GDP created per total direct water usage (DGC/TDW), total GDP created per total water usage (TGC/TWU), and indirect GDP created per total indirect water usage (IGC/TIW).

$$DGC / TDW = \frac{\left(v_{ij} a_{ij}\right)}{\left(w_{di}^* a_{ij}\right)} \tag{22}$$

$$TGC / TWU = \frac{\left(v_{ij} a_{ij}\right)}{\left(\text{sum}\left(w_{di}^*\right)_{\text{column}}\right)} \tag{23}$$

$$\mathrm{IGC/TIW} = \frac{\left(v_{ij}a_{ij}\right) - v_{ij}}{\left(w^*_{di}a_{ij}\right) - w^*_{di}} \tag{24}$$

2.5. Matrix of Inter-Sectoral Water Relationships and Associated Matrices

At this point, the I-O model of water usage and the indicators have been defined along with the matrix of inter-sectoral water relationship. The formulas can be explained by using the indicators. In section of input-output model of water usage, we defined (w_{di}^y) as the quantity of water directly consumed by sector i to satisfy its own demand. This variable (w_{di}^y) can be obtained as

$$w_d^y = \hat{w}_d^* y \tag{25}$$

Equation (11) can be substituted with this expression. Placing the vector (y) on the diagonal yields

$$W = \left(I - Q\right)^{-1} \hat{w}_d^* \hat{y} \tag{26}$$

where W is the vector of the total amount of water consumed by the economy (w_t), which becomes the matrix of inter-sectoral water relationships (n×n). The matrix lists all the water transactions between productive sectors expressed in cubic meters.

From the matrix of inter-sectoral water relationships and a matrix of water distribution coefficients can be obtained. Equation (8) denotes the technical coefficients of water usage defined as the quantity of water consumed directly by sector j. The columns in the matrix of technical coefficients express the quantity of water in each sector of sector j. These coefficients can also be expressed according to the indicator of direct usage defined as

$$q_{ij} = \frac{w_{ij}}{w_{dj}} = \frac{w^*_{di}}{w^*_{dj}} a_{ij} \tag{27}$$

Similar to Eq. (12), which defines the technical coefficients of production, Eq. (28) can be represented as the quotient between the relationships of sectors i and j in relation to the production of j.

$$q_{ij} = \frac{w_{di}/x_i}{w_{dj}/x_j} \frac{x_{ij}}{x_j} \tag{28}$$

By definition of w_{ij}, y and w_{dj},

$$q_{ij} = \frac{w_{di}x_{ij}}{w_{dj}x_i} = \frac{w_{ij}}{w_{dj}} \tag{29}$$

3. Results and Discussion

This section discusses the results of the analysis of the I-O model, the matrix of inter-sectoral water relationships, the indicators of water usage, and the growth of the GDP derived from the formulas in the model. Table 3 displays the direct water usage (w_d), percentage of total direct water usage, indicators of direct water usage per unit produced (w_d^*), and indicators of total water usage (w^*). The table likewise shows the ratios of the direct and total water usage indicators, which can be divided between direct and indirect water usage. Due to the limitation of space, the outcomes from the I-O model shown in this paper are those of 30 sectors having the largest direct water usage. Among these top water users, there are 16 agriculture sectors included and the sum of their water demands are approximately 136,349 MCM, which account for 96.15%

of the sum of 30 sectors. The data indicate that the manufacturing and service sectors have six (2,848 MCM, 2.01%) and eight (1,687 MCM, 1.84%) sub-sectors, respectively. Hence, the results reveal that the agricultural sector is the main consumer of water resources in Thailand, especially the paddy (1) is the biggest cultivation in the country.

Table 3. Direct water usage (w_d) (millions of m^3, MCM), indicator of direct water usage per currency unit produced (w_d^*), and indicator of total water usage (w^*, m^3/a million Baht).

Sectors	wd	%wd	wd*	w*	wd/wt (%)	(wt-wd)/wt (%)
(1)	65,657.3	46.30	174,075.3	181,876.8	95.7	4.3
(16)	37,022.5	26.11	101,411.6	106,710.7	95.0	5.0
(11)	13,216.4	9.32	284,511.4	290,125.5	98.0	1.9
(4)	7,089.4	5.00	162,784.5	188,842.8	86.2	13.8
(2)	4,042.1	2.85	93,919.5	103,858.3	90.4	9.6
(10)	3,161.1	2.23	734,270	746,486.2	98.4	1.6
(8)	3,018.4	2.13	9,867	10,434.7	94.6	5.4
(55)	2,548.9	1.80	15,870.6	23,923.6	66.3	33.7
(9)	1,019	0.72	15,935.1	17,451.8	91.3	8.7
(15)	669.6	0.47	110,111.8	110,510	99.6	0.4
(29)	644.2	0.45	13,523.7	19,340.6	69.9	30.1
(137)	642.8	0.45	10,987.7	11,661.2	94.2	5.8
(135)	458.7	0.32	641.2	1,068.5	60.0	40.0
(28)	258.3	0.18	1,636	3,732.9	43.8	56.2
(21)	189.3	0.13	1,557.9	21,727.7	7.2	92.8
(148)	187.8	0.13	551.3	2,606.6	21.1	78.8
(163)	130.8	0.09	311.1	493.1	63.1	36.9
(164)	123.2	0.09	235.2	958.5	24.5	75.5
(6)	121.6	0.09	3,082.4	3,227.2	95.5	4.5
(30)	109	0.08	1,748.3	2,354	74.3	25.7
(18)	99.2	0.07	2,288.4	17,078.5	13.4	86.6
(7)	84.6	0.06	224.1	857.3	26.1	73.9
(147)	62.2	0.04	104.4	13,314.5	0.8	99.2
(81)	60.7	0.04	282	1,327.9	21.2	78.8
(19)	55.6	0.04	734	32,118.7	2.3	97.7
(67)	46.5	0.03	283.5	585.8	48.4	51.6
(84)	44.2	0.03	84.1	621.3	13.5	86.5
(167)	43	0.03	86.5	1,302.2	6.6	93.3
(78)	38.9	0.03	393.1	653.8	60.1	39.9
(159)	38.5	0.03	97.4	310.6	31.3	68.6

The results from the analysis also show the indicator of direct water usage per currency unit produced (w_d^*). The indicator shows evidence of the high-water usage of every sector because it presents a high usage per unit produced. The top three consumers for the agricultural sector are the paddy (1), rubber (16), and oil palm (11) areas, with usages of 174,075, 101,412, and 284,511 m^3, respectively. The outcomes demonstrate the high-water usage in comparison with production and the crucial influence of sectors on the usage of limited water resources in Thailand. Although the sectors consume a significantly small fraction from the total direct water usage, they should not be considered as negligible because if the indicator of direct water usage per currency unit produced is considered, the situation changes [31]. For instance, the sector "Coffee and tea (15)" consumes the least water directly, but its production is also low; thus, it presents the highest water usage per currency consumed. The other sectors show a similar trend: cassava (4), maize (2), and cattle and buffalo (18). In addition, some sectors display low direct water usage per unit produced, but they are

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important to other sectors as the main suppliers in the economic structure. The indicator of total water usage (w^*) shows that the following sectors entail indirect water usage: poultry (21), hotels and places of loading (148), cattle and buffalo (18), restaurants and drinking places (147), and swine (19). These sectors consume only a small amount of water directly in their production, but their suppliers of intermediate inputs use a large amount of water in the production processes.

We further analyze the ratio for comparison between the indicators of direct and total water usage (w_d/w_t) and the indicators of indirect and total water usage (w_t- w_d/w_t) in the last two columns of Table 3. The results confirm that the above analysis correctly considered the direct and indirect water usage in each sector. The top five sectors with direct water usage from whole sectors are coffee and tea (15), coconut (10), oil palm (11), paddy (1), and beans and nuts (6), with water usage of approximately 99.6%, 98.4%, 98.1%, 95.7%, and 95.5%, respectively. These sectors mainly consume surface and ground water to produce their products.

Table 4. Water usage multiplier (wum) and indicator of indirect water usage (iwum).

Sectors	NS	wum	iwum
Paddy	(1)	1.04	0.04
Rubber	(16)	1.05	0.05
Oil palm	(11)	1.02	0.02
Cassava	(4)	1.16	0.16
Maize	(2)	1.11	0.11
Coconut	(10)	1.02	0.02
Fruits	(8)	1.06	0.06
Sugar	(55)	1.51	0.51
Sugar cane	(9)	1.10	0.10
Coffee and tea	(15)	1.00	0.00
Inland fishing	(29)	1.43	0.43
Water work and supply	(137)	1.06	0.06
Electricity	(135)	1.67	0.67
Ocean and coastal fishing	(28)	2.28	1.28
Poultry	(21)	13.95	12.95
Hotels and places of loading	(148)	4.73	3.73
Real estate	(163)	1.58	0.58
Business services	(164)	4.07	3.07
Beans and nuts	(6)	1.05	0.05
Coal and lignite	(30)	1.35	0.35
Cattle and buffalo	(18)	7.46	6.46
Vegetable	(7)	3.83	2.83
Restaurants, drinking places	(147)	127.56	126.56
Pulp, paper and paperboard	(81)	4.71	3.71
Swine	(19)	43.76	42.76
Spinning	(67)	2.07	1.07
Basic industrial chemicals	(84)	7.38	6.38
Education	(167)	15.05	14.05
Saw mills	(78)	1.66	0.66
Post and telecommunication	(159)	3.19	2.19

(NS = Number of sectors in I-O Model of Thailand)

As a result, the agricultural sector is a significant sector that puts pressure on the water resources of Thailand. Therefore, this sector needs to develop the new production technology to increase productivity and reduce water usage. With regard to the indirect water usage in the agricultural sector, the horticulture and livestock sector, including swine (19), poultry (21), cattle and buffalo (18), and vegetable (7), are the main indirect consumers.

Most service and manufacturing sectors record high indirect water usage relative to the agricultural sector. These sectors connect with the other sectors because they are located in the second and third sequences of the supply chain of production. The top sectors with regard to indirect water usage are restaurants and drinking places (147); education (167); basic industrial chemicals (84); hotels and places of loading (148); and pulp, paper, and paperboard (81), with usage of 99.5%, 93.4%, 86.5%, 78.9%, and 78.8%, respectively. These sectors consume less water or direct water than the agricultural sector, but they consume products from other sectors, which influence their high indirect water usage. These sectors show a huge potential to exert a "drag" effect on the economy in terms of water use.

The above outcomes in Table 4 can be validated and explained by analyzing wum, iwum, and the "drag effect" in terms of quantity (Table 3). We consider wum and iwum values because if only direct water usage is taken into account, sectors such as restaurants and drinking places (147) and swine (19) would be disregarded due to the fact that their insignificant direct water usage. The low values of wum indicate that these sectors have direct water usage and a small drag effect. That is, if the final demand of a given sector increases by one unit, the total water usage is increased by the wum value of each sector, e.g., 1.04 for paddy (1) and 1.05 for rubber (16). The top four sectors with the highest indirect water usage are restaurants and drinking places (147), swine (19), education (167), and poultry (21), with indirect water usage of 126.56, 42.76, 14.05, and 12.95 m^3, respectively. By considering these sectors in Table 4, we observe that the linkages of indirect water usage relative to the total water usage are 99.22%, 97.71%, 93.35%, and 92.83%, respectively.

The results demonstrate that the sectors with relatively high indirect water usage are normally known as the "driving force" of Thai economy, because the strong influence of their product demand affects the production of the remaining economic agents. Nonetheless, existing economic policies take into account the environmental factors that play an important role in Thailand's productive activities and not the productive criteria of sectors. The limited water resources may put pressure on production and lead to crucial situations such as that in the large manufacturing area of Thailand, i.e. the case of water shortage of Rayong Province in year 2005 [32].

Table 5, 6 and 7 show the results of the ratios between growth GDP and water usage, including DGC/TDW, TGC/TWU, and IGC/TIW. As shown in the results of DGC/TDW in Table 5, the first 30 sectors incur minimal water usage, but they can generate the highest GDP. These sectors are mainly service and manufacturing sectors. Thus, if we consider DGC/TDW, it cannot reflect the reality of growth GDP and water usage. The top three sectors for DGC/TDW are public works for agriculture and forestry (140), petroleum and natural gas (31), construction of electric plants (142), construction of communication facilities (143), and other non-ferrous metals (35). For TGC/TWU, the first 30 sectors belong to the upstream industries, and they consume the least amount of water in the whole supply chain, but they can generate the high value of GDP. These sectors include other cereals (3), silkworm (23), kenaf and jute (12), limestone (39), and coastal and inland water transport (154). Finally, Table 7 presents the result of IGC/TIW, which is the ratio of GDP created and indirect water usage. This result unveils the relationship of GDP created by each sector and the water consumed in its backward supply chain. This result emphasizes the significance of incorporating the indirect use of water into the analysis. The sectors having the high value of IGC/TIW are those slightly consume water in their production processes.

Moreover, if we observe DGC/TDW in Table 6 and 7, some values are equal to zero. This study explains two main reasons; those sectors cannot generate the GDP from the direct water usage in their productive processes such as kenaf and jute (12), agricultural services (24), and tobacco processing (65), and this study has only the total water usage data from each sector. The I-O model cannot analyze the direct water usage of some sectors. As the results, some sectors do not represent the actual value of direct water usage. This is limitation of I-O model in analysis matters.

However, the GDP generation and water usage are occurring in the network of supply chain which produces the intermediate inputs for these sectors. Therefore, this revelation extends the conventional understanding and provides the insight on hidden contribution of water in Thai economy.

Table 5. The direct GDP created (Baht) per the total direct water usage (m^3), (DGC/TDW).

Sectors	NS	DGC/TDW	TGC/TWU	IGC/TIW
Public works for agriculture and forestry	140	693,340	1,241	572
Petroleum and natural gas	31	551,320	3,295	603
Construction of electric plants	142	455,874	541	431
Construction of communication facilities	143	396,574	1,295	526
Other non-ferrous metals	35	386,058	1,188	418
Wearing apparel	72	349,622	981	544
Limestone	39	209,733	2,035	309
Other root crops	5	146,541	1,472	282
Office and household machinery and appliances	116	139,175	1,343	419
Other mining and quarrying	41	126,820	684	371
Other construction	144	106,961	992	456
Banking services	160	101,109	2,670	408
Jewellery and related articles	132	88,700	1,971	571
Ship building and repairing	123	83,230	1,241	408
Knitting	71	74,981	829	352
Coastal and inland water transport	154	68,431	3,534	889
Watches and clocks	131	65,600	526	143
Made-up textile goods	70	62,296	482	241
Weaving	68	59,067	935	433
Personal service	178	44,528	246	66
Soap and cleaning preparations	89	44,132	72	32
Breweries	63	39,208	217	71
Other insurance services	162	36,565	1,701	323
Petrochemical products	86	31,938	2,361	633
Business and labour associations	170	29,913	798	180
Drugs and medicines	88	26,195	223	88
Insulated wire and cable	120	26,174	1,096	370
Other petroleum products	94	23,790	5,972	368
Cutlery and hand tools	108	21,887	1,397	468
Non-agriculture public works	141	21,356	685	454

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Table 6. The total GDP created (Baht) per the total water usage (m^3), (TGC/TWU).

Sectors	NS	TGC/TWU	DGC/TDW	IGC/TIW
Other cereals	3	15,440	-	3,313
Silkworm	23	14,148	-	1,276
Kenaf and jute	12	7,743	-	1,856
Charcoal and firewood	26	7,468	-	977
Tobacco processing	65	6,184	-	3,086
Other petroleum products	94	5,972	23,790	368
Agricultural services	24	4,903	-	637
Other forest products	27	4,759	-	638
Logging	25	3,700	-	345
Coastal and inland water transport	154	3,534	68,431	889
Tobacco	14	3,503	-	584
Petroleum and natural gas	31	3,295	551,320	603
Tobacco products	66	3,066	-	1,096
Life insurance services	161	2,676	10,485	471
Banking services	160	2,670	101,109	408
Petrochemical products	86	2,361	31,938	633
Land transport support service	152	2,233	11,747	378
Post and telecommunication	159	2,074	4,635	590
Other crops for textile and matting	13	2,065	-	477
Limestone	39	2,035	209,733	309
Jewellery and related articles	132	1,971	88,700	571
Tin ore	33	1,927	-	556
Jute mill products	74	1,890	16,078	519
Railways	149	1,842	3,640	425
Retail trade	146	1,813	-	169
Pipe line and gas distribution	136	1,776	3,067	1,206
Other insurance services	162	1,701	36,565	323
Structure metal products	110	1,635	4,455	558
Water transport services	155	1,605	3,054	398
Real estate	163	1,563	2,122	595

Table 7. The indirect GDP created (Baht) per the total indirect water usage (m^3), (IGC/TIW).

Sectors	NS	IGC/TIW	DGC/TDW	TGC/TWU
Other cereals	3	3,313	-	15,440
Tobacco processing	65	3,086	-	6,184
Kenaf and jute	12	1,856	-	7,743
Silkworm	23	1,276	-	14,148
Petroleum refineries	93	1,221	7,158	1,491
Pipe line and gas distribution	136	1,206	3,067	1,776
Tobacco products	66	1,096	-	3,066
Charcoal and firewood	26	977	-	7,468
Coastal and inland water transport	154	889	68,431	3,534
Other non-metallic products	104	818	471	619
Saw mills	78	796	413	546
Coffee and tea	15	723	2	3
Cassava	4	685	4	4
Paddy	1	671	4	4
Concrete and cement products	103	664	1,391	888
Iron and steel	105	641	440	539
Other forest products	27	638	-	4,759
Agricultural services	24	637	-	4,903
Petrochemical products	86	633	31,938	2,361
Other fabricated metal products	111	631	1,309	972
Water work and supply	137	616	55	70
Cement	102	611	3,123	1,109
Petroleum and natural gas	31	603	551,320	3,295
Coconut	10	596	1	1
Real estate	163	595	2,122	1,563
Post and telecommunication	159	590	4,635	2,074
Tobacco	14	584	-	3,503
Public works for agriculture and forestry	140	572	693,340	1,241
Jewellery and related articles	132	571	88,700	1,971
Ceramic and earthen ware	99	569	1,079	741

Table 8 shows the matrix of inter-sectoral water relationships 26×26 sectors because the limitation of displayed results. Column j lists the backward relationship in which sector j purchases inputs from sector i. In other words, sector i is the supplier providing intermediate input to sector j. On the other hand, the interpretation of relationship of row i identifies the forward relationship in which sector i functions as the supplier of sector j. From the matrix of inter-sectoral water relationships, the matrix of distribution coefficients (Table 9) can be obtained. This matrix shows the water transaction coefficient between sectors. The distribution coefficients in rows and columns are of high values, especially the agricultural sector (1-29). In the supply chain embedded in the economic structure, the agricultural sector is key distributor of inputs of the manufacturing and service sectors, and it consumes high water content. Examples of sectors include paddy (1), cassava (4), and sugarcane (9). If agricultural goods are not obtained because of natural disasters, then other sectors will cease operation.

4. Conclusion

This research explores water usage in Thailand in 2010 by using a framework of the I-O model. The model provides indicators and matrices that can be applied as decision-making tools for economic planning under the limitation of environmental factors, especially water resources. We mainly conclude that Thai economy comprises a water usage network of 180×180 sectors, which can be visualized as a whole water usage system.

The results can be summarized from the analysis of indicators of water usage. The analysis is important to understand direct and indirect usage. If we consider direct water usage alone, we will not be able to visualize indirect water usage, which plays an important role. The agricultural sector marks the highest rate of direct water usage and the lowest rates of indirect water usage. By contrast, the manufacturing and service sectors present low indicators of direct water usage and high indicators of indirect water usage, including the sectors of restaurants and drinking places (147) and basic industrial chemicals (84). The results can facilitate the planning of productive processes of Thailand's economy. Similarly, the analysis of the three ratios, namely, DGC/TDW, TGC/TWU, and IGC/TIW, reflects the real GDP created from water usage. These three ratios enhance our insight regarding the actual contribution of water in the economic structure. Particularly if we consider only the growth of GDP per direct water usage, the results will be misleading. This is because each sector also consumes the water indirectly through its usages of raw materials and intermediates inputs. Hence the I-O model enables the complete estimation of both direct and indirect water usages revealing the actual association between the GDP created and water used.

All outcomes of this research indicate that Thailand must increase the potential of its production processes and technology, especially in the agricultural sector, to decrease water usage. The manufacturing and service sectors should be aware of the means to save and effectively use water. We also emphasize that the growth of economy could incur a higher water demand. However, climate change could affect water resources, thereby adding to the stress brought about by limited water resources. This study can be a part of the further analysis of the "water pricing policy" of Thailand because it shows the detailed linkages between economic activity and water usage. This study can also extend the research into the issues of employment by showing the importance of water in labour generation in each sector. Furthermore, Structural Path Analysis and Structural Decomposition Analysis techniques can also be applied to examine the water used in supply chains and the structural changes in water used each year, respectively.

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Table 8. Matrix of inter-sectoral water relationships (W, in millions of cubic meters).

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	Sum
1	7,419	6,529	4.2	550.2	130	110,741	1,194	417	316	1,525	133	21,371	281	40	40	2,145	1,021	236	785	578	8,088	966	162	35	2,119	1,518	**168,342**
2	0.5	24.5	0.0	0.1	0.2	325.4	0.3	0.6	0.1	0.6	0.1	0.2	0.2	0.1	0.1	1.8	13.8	0.3	1.1	3.0	53.9	1.5	0.6	0.1	4.8	2.3	**436**
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
4	1.0	24.0	0.1	49.3	0.5	363.6	1.0	0.5	0.3	7.4	0.2	0.5	0.4	0.2	0.2	2.7	2.0	0.7	2.8	7.0	152.6	3.5	1.4	0.2	17.7	1.8	**642**
5	0.8	0.6	0.0	0.3	0.9	7.7	1.1	6.6	2.0	5.4	1.2	3.4	23.9	12.8	1.6	22.9	7.7	62.6	23.3	3.3	6.8	4.2	1.9	1.7	7.6	0.9	**211**
6	12.6	40.3	0.1	3.4	1.5	771.6	567	3.7	39.4	30.6	1.3	8.1	2.2	1.0	0.7	12.5	12.5	15.3	6.4	10.6	146.6	17.3	8.1	1.1	36.4	14.8	**1,765**
7	0.0	0.0	0.0	0.0	0.0	0.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.2	3.8	0.5	0.1	0.0	0.2	0.5	**7.2**
8	0.2	0.0	0.0	0.1	0.1	0.4	0.1	57	0.1	1.5	0.1	1.2	0.2	0.1	0.0	1.9	3.0	0.1	0.4	0.6	1.1	0.7	0.5	0.1	1.4	1.1	**72**
9	0.7	0.2	0.0	0.1	1.1	2.4	1.4	2.1	34.7	2.7	0.9	0.9	1.3	0.4	0.4	7.4	3.5	1.4	1.9	1.6	1.5	3.4	8.6	0.6	21.1	1.2	**102**
10	10.6	0.6	0.0	0.3	0.7	8.0	2.2	3.4	2.1	17.1	4.1	6.9	2.5	0.8	0.7	16.1	4.1	0.9	3.1	0.9	2.4	2.4	0.5	0.1	6.2	1.0	**98**
11	0.3	0.0	0.0	0.2	0.5	0.5	0.1	0.2	0.0	0.5	1.3	0.2	0.3	0.2	0.1	1.2	0.2	0.5	1.1	0.1	0.2	2.9	0.1	0.0	0.5	0.1	**11.3**
12	0.7	0.1	0.0	0.2	0.6	1.3	0.3	1.7	0.3	0.8	0.2	6.6	0.4	0.1	0.4	20.8	5.2	0.3	5.5	1.2	0.6	3.1	0.3	0.1	2.4	1.1	**54.4**
13	0.2	0.1	0.0	0.0	0.1	0.5	0.3	0.1	0.1	0.4	0.1	0.1	4.7	0.1	0.4	5.3	1.0	0.2	34.2	0.2	0.5	0.4	0.3	0.2	0.8	0.6	**51.2**
14	0.3	0.0	0.0	0.0	0.3	0.7	0.5	0.3	0.1	0.3	0.1	0.3	0.9	22.0	9.5	43.8	9.0	0.3	7.8	0.2	0.3	1.5	0.3	0.1	1.9	1.0	**101.5**
15	0.3	0.1	0.0	0.0	0.1	1.7	2.1	0.4	0.2	0.5	0.1	0.4	0.2	0.2	0.9	10.1	0.9	0.4	4.2	0.1	0.5	0.9	0.1	0.0	1.0	0.2	**25.5**
16	1.2	0.1	0.0	0.2	0.9	1.2	0.2	0.3	0.1	0.4	0.2	0.3	0.6	0.2	0.1	32.4	0.7	0.9	4.0	0.4	0.5	7.0	0.4	0.1	1.9	0.3	**54.6**
17	0.8	0.1	0.0	0.1	0.3	0.6	0.4	0.5	0.2	0.7	0.2	0.3	0.4	0.1	0.9	6.1	23.0	0.2	11.9	0.8	0.5	0.9	0.4	0.1	2.9	0.4	**52.5**
18	11.6	7.1	0.2	3.0	10.8	84.9	18.0	68	14.6	49.1	9.9	38.8	31.8	20.3	9.2	199.5	40.2	73.3	41.9	33.8	95.4	58.1	19.1	31.8	106.6	4.6	**1,082**
19	0.1	0.1	0.0	0.0	0.1	0.2	0.1	0.1	0.0	0.2	0.1	0.1	0.1	0.0	0.0	0.9	0.2	0.2	0.2	0.1	0.3	0.3	0.5	0.2	1.0	0.0	**5.1**
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	**0**
21	1.3	0.1	0.2	0.0	0.9	1.4	0.4	0.8	0.5	1.1	0.6	0.6	0.6	0.3	0.2	5.0	2.2	1.3	2.4	4.2	1.0	5.1	2.0	0.3	7.2	0.6	**40.2**
22	1.1	0.3	0.0	0.1	2.6	3.5	1.0	1.8	0.8	2.9	0.9	2.2	2.0	0.7	0.6	13.5	3.6	1.9	13.2	3.2	2.5	21.5	4.3	0.5	9.8	1.1	**95.4**
23	0.3	0.1	0.0	0.0	0.1	0.4	0.1	0.2	0.1	0.2	0.1	0.1	0.1	0.1	0.1	0.7	0.2	0.4	0.3	0.3	0.2	0.6	0.5	0.2	0.3	0.1	**5.5**
24	0.6	0.1	0.0	0.1	0.7	1.7	0.3	0.9	0.2	1.1	0.5	0.7	0.4	0.2	0.3	4.5	1.7	1.1	1.5	2.1	2.2	4.1	6.2	0.6	5.6	0.5	**37.8**
25	1.9	0.6	0.0	0.5	16.9	8.3	4.8	4.6	2.8	6.8	12.3	3.3	4.4	1.1	1.1	24.2	7.9	9.7	11.0	4.1	8.8	23.7	9.5	3.6	33.7	0.9	**206.7**
26	0.2	0.1	0.0	0.1	0.2	2.0	0.5	0.9	0.4	0.8	0.2	0.2	0.8	0.1	0.1	3.0	0.7	0.7	0.7	3.2	0.5	1.4	0.4	0.1	1.7	0.2	**18.9**
Sum	**7,466**	**6,629**	**5.0**	**608.2**	**170.2**	**112,329**	**1,797**	**572**	**415**	**1,656**	**167.6**	**21,447**	**360**	**101.2**	**67.2**	**2,581**	**1,165**	**409.2**	**964.3**	**658.8**	**8,571**	**1,131**	**227.9**	**76.5**	**2,391**	**1,554**	

Table 9. Matrix of water transaction coefficient for the Thailand economy in 2010.

Sector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
1	232.4	61.5	0.0	1.6	1,051.7	12,319.4	320.0	984.8	120.6	1,991.6	20.9	1137.2	124.9	2.3	22.5	554.4	625.3	2.2	5,012.8	0.0	123.8	105.4	57.5	0.3	365.5	42.1
2	0.1	0.2	0.0	0.0	1.6	42.7	0.1	2.1	0.1	0.3	0.0	0.0	0.1	0.0	0.0	0.6	9.7	0.0	7.5	0.0	0.8	0.2	0.2	0.0	0.6	0.1
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.2	0.1	0.0	0.1	4.1	27.1	0.6	1.4	0.1	7.8	0.0	0.0	0.1	0.0	0.1	0.9	1.3	0.0	19.1	0.0	2.2	0.5	0.6	0.0	2.2	0.1
5	0.2	0.0	0.0	0.0	4.1	1.3	0.4	16.0	0.5	2.0	0.2	0.2	2.7	0.7	0.7	8.3	5.8	0.2	134.2	0.0	0.1	0.5	0.6	0.0	1.2	0.0
6	2.6	0.3	0.0	0.0	8.4	309.5	83.3	10.1	7.5	18.0	0.2	0.4	0.5	0.1	0.4	4.5	4.5	0.1	36.8	0.0	2.2	1.8	2.3	0.0	4.8	0.4
7	0.0	0.0	0.0	0.0	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0
8	0.4	0.0	0.0	0.0	0.6	0.1	0.0	162.6	0.1	0.5	0.0	0.1	0.0	0.0	0.0	1.0	1.4	0.0	3.3	0.0	0.0	0.2	0.1	0.0	0.3	0.0
9	0.1	0.0	0.0	0.0	4.6	0.6	0.4	6.7	16.2	2.4	0.1	0.1	0.2	0.0	0.2	2.2	2.2	0.0	13.2	0.0	0.0	0.5	2.4	0.0	1.3	0.0
10	2.3	0.0	0.0	0.0	6.1	1.1	0.6	7.9	0.7	11.6	0.7	0.5	0.7	0.0	0.4	5.4	2.5	0.0	16.4	0.0	0.0	0.4	0.2	0.0	1.7	0.0
11	0.1	0.0	0.0	0.0	3.0	0.1	0.0	0.5	0.0	0.2	0.6	0.0	0.1	0.0	0.0	0.4	0.2	0.0	9.6	0.0	0.0	0.6	0.0	0.0	0.1	0.0
12	0.2	0.0	0.0	0.0	3.9	0.3	0.1	6.1	0.1	0.7	0.0	0.9	0.1	0.0	0.3	5.8	4.0	0.0	23.1	0.0	0.0	0.3	0.1	0.0	0.3	0.0
13	0.1	0.0	0.0	0.0	0.6	0.1	0.2	0.4	0.0	0.4	0.0	0.0	0.8	0.0	0.2	2.2	1.2	0.0	111.4	0.0	0.0	0.1	0.1	0.0	0.1	0.0
14	0.2	0.0	0.0	0.0	2.2	0.1	0.2	0.8	0.0	0.2	0.0	0.0	0.1	1.3	2.9	14.3	7.6	0.0	79.0	0.0	0.0	0.2	0.1	0.0	0.2	0.0
15	0.1	0.0	0.0	0.0	1.1	0.2	1.1	1.0	0.1	0.3	0.0	0.0	0.0	0.0	0.5	3.6	0.4	0.0	9.8	0.0	0.0	0.1	0.0	0.0	0.2	0.0
16	0.3	0.0	0.0	0.0	8.9	0.2	0.1	0.8	0.0	0.2	0.0	0.0	0.1	0.0	0.0	7.3	0.6	0.0	39.7	0.0	0.0	0.6	0.1	0.0	0.2	0.0
17	0.2	0.0	0.0	0.0	0.9	0.1	0.3	1.8	0.1	0.3	0.0	0.0	0.1	0.0	0.9	5.6	4.1	0.0	27.8	0.0	0.0	0.2	0.1	0.0	0.4	0.0
18	2.2	0.1	0.0	0.0	48.4	14.6	6.1	169.8	5.0	30.5	2.0	2.6	6.2	1.2	4.7	62.9	27.9	0.7	224.2	0.0	0.9	6.6	5.7	0.2	14.1	0.1
19	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.2	0.0	1.1	0.0	0.0	0.0	0.1	0.0	0.1	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21	0.3	0.0	0.0	0.0	5.6	0.3	0.2	2.3	0.2	0.7	0.1	0.0	0.1	0.0	0.1	1.8	1.4	0.0	14.2	0.0	0.0	0.6	0.8	0.0	1.0	0.0
22	0.3	0.0	0.0	0.0	24.8	0.7	0.4	5.0	0.3	1.7	0.1	0.1	0.4	0.0	0.3	4.2	2.7	0.0	124.2	0.0	0.0	2.8	1.2	0.0	1.0	0.0
23	0.0	0.0	0.0	0.0	0.4	0.1	0.0	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.2	0.1	0.0	2.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0
24	0.1	0.0	0.0	0.0	3.0	0.3	0.1	2.6	0.1	0.6	0.1	0.1	0.1	0.0	0.2	1.8	1.3	0.0	8.0	0.0	0.0	0.6	2.4	0.0	0.7	0.0
25	0.3	0.0	0.0	0.0	52.9	2.3	1.7	13.7	1.1	6.1	1.8	0.3	1.3	0.1	0.6	9.2	6.3	0.2	88.0	0.0	0.1	4.1	3.0	0.0	4.1	0.0
26	0.0	0.0	0.0	0.0	0.9	0.3	0.2	2.6	0.1	1.1	0.0	0.0	0.2	0.0	0.1	1.1	0.5	0.0	3.8	0.0	0.0	0.2	0.1	0.0	0.5	0.0

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Appendix 1. The Convertor of Input-Output Table Classification in Thailand.

26 x 26 Sectors		**180 x 180 Sectors**	
001	Crops (001-017, 024)	001	Paddy
		002	Maize
		004	Cassava
		006	Beans and Nuts
		007	Vegetables
		008	Fruits
		009	Sugarcane
		016	Rubber
		003	Other Cereals
		005	Other Root Crops
		010	Coconut
		011	Oil Palm
		012	Kenaf and Jute
		013	Crops for Textile and Matting
		014	Tobacco
		015	Coffee and Tea
		017	Other Agricultural Products
		024	Agricultural Services
002	Livestock (018-023)	018	Cattle and Buffalo
		019	Swine
		020	Other Livestock
		021	Poultry
		022	Poultry Products
		023	Silk Worm
003	Forestry (025-027)	025	Logging
		026	Charcoal and Firewood
		027	Other Forestry Products
004	Fishery (028-029)	028	Ocean and Coastal Fishing
		029	Inland Fishing
005	Mining and Quarrying (030-041)	030	Coal and Lignite
		031	Petroleum and Natural Gas
		032	Iron Ore
		033	Tin Ore
		034	Tungsten Ore
		035	Other Non-ferrous Metal Ore
		036	Fluorite
		037	Chemical Fertilizer Minerals
		038	Salt Evaporation
		039	Limestone
		040	Stone Quarrying
		041	Other Mining and Quarrying
006	Food Manufacturing (042-061)	042	Slaughtering
		043	Canning Preserving of Meat

26 x 26 Sectors		180 x 180 Sectors	
		044	Dairy Products
		045	Canning of Fruits and Vegetables
		046	Canning Preserving of Fish
		047	Coconut and Palm Oil
		048	Other Vegetable Animal Oils
		049	Rice Milling
		050	Tapioca Milling
		051	Drying and Grinding of Maize
		052	Flour and Other Grain Milling
		055	Sugar
		053	Bakery Products
		054	Noodles and Similar Products
		056	Confectionery
		057	Ice
		058	Monosodium Glutamate
		059	Coffee and Tea Processing
		060	Other Food Products
		061	Animal Feed
007	Beverages and Tobacco Products (062-066)	062	Distilling Blending Spirits
		063	Breweries
		064	Soft Drinks
		065	Tobacco Processing
		066	Tobacco Products
008	Textile Industry (067-074)	067	Spinning
		068	Weaving
		069	Textile Bleaching and Finishing
		070	Made-up Textile Goods
		071	Knitting
		072	Wearing Apparels Except Footware
		073	Carpets and Rugs
		074	Cordage Rope and Twine Products
009	Paper Products and Printing (081-083)	081	Pulp Paper and Paperboard
		082	Paper Products
		083	Printing and Publishing
010	Chemical Industries (084-092)	084	Basic Industrial Chemicals
		086	Synthetic Resins and Plastics
		085	Fertilizer and Pesticides
		087	Paints Varnishes and Lacquers
		088	Drugs and Medicines
		089	Soap and Cleaning Preparations
		090	Cosmetics
		091	Matches
		092	Other Chemical Products
011	Petroleum Refineries (093-094)	093	Petroleum Refineries
		094	Other Petroleum Products
012	Rubber and Plastic Products (095-098)	095	Rubber Sheets and Block Rubber

26 x 26 Sectors		**180 x 180 Sectors**	
		096	Tyres and Tubes
		097	Other Rubber Products
		098	Plastic Wares
013	Non-metallic Products (099-104)	102	Cement
		103	Concrete and Cement Products
		099	Ceramic and Earthen Wares
		100	Glass and Glass Products
		101	Structural Clay Products
		104	Other Non-metallic Products
014	Basic Metal (105-107)	105	Iron and Steel
		106	Secondary Steel Products
		107	Non-ferrous Metal
015	Fabricated Metal Products (108-111)	108	Cutlery and Hand Tools
		109	Furniture and Fixtures Metal
		110	Structural Metal Products
		111	Other Fabricated Metal Products
016	Machinery (112-128)	112	Engines and Turbines
		113	Agricultural Machinery
		114	Wood and Metal Working Machinery
		115	Special Industrial Machinery
		116	Office and Household Machinery
		117	Electrical Industrial Machinery
		118	Radio and Television
		119	Household Electrical Appliances
		120	Insulated Wire and Cable
		121	Electric Accumulator & Battery
		122	Other Electrical Apparatuses & Supplies
		125	Motor Vehicle
		126	Motorcycle, Bicycle & Other Carriages
		127	Repairing of Motor Vehicle
		123	Ship Building
		124	Railway Equipment
		128	Aircraft
017	Other Manufacturing (075-080, 129-134)	075	Tanneries Leather Finishing
		076	Leather Products
		077	Footwear Except Rubber
		078	Saws Mills
		079	Wood and Cork Products
		080	Furniture and Fixtures Wood
		129	Scientific Equipments
		130	Photographic & Optical Goods
		131	Watches and Clocks
		132	Jewelry & Related Articles
		133	Recreational and Athletic Equipment
		134	Other Manufacturing Goods
018	Electricity and Water Works (135-137)	135	Electricity

26 x 26 Sectors		180 x 180 Sectors	
		136	Pipe Line
		137	Water Supply System
019	Construction (138-144)	138	Residential Building Construction
		139	Non-Residential Building Construction
		140	Public Works for Agriculture & Forestry
		141	Non-Agricultural Public Works
		142	Construction of Electric Plant
		143	Construction of Communication Facilities
		144	Other Constructions
020	Trade (145-146)	145	Wholesale Trade
		146	Retail Trade
021	Restaurants and Hotels (147-148)	147	Restaurant and Drinking Place
		148	Hotel and Lodging Place
022	Transportation and Communication (149-159)	149	Railways
		150	Route & Non Route of Road Passenger Trans.
		151	Road Freight Transport
		152	Land Transport Supporting Services
		153	Ocean Transport
		154	Coastal & Inland Water Transport
		155	Water Transport Services
		156	Air Transports
		157	Other Services
		158	Silo and Warehouse
		159	Post and Telecommunication
023	Banking and Insurance (160-162)	160	Banking Services
		161	Life Insurance Service
		162	Other Insurance Service
024	Real Estate (163)	163	Real-estate
025	Services (164-178)	164	Business Service
		165	Public Administration
		166	Sanitary and Similar Services
		167	Education
		168	Research
		169	Hospital
		170	Business and Labor Associations
		171	Other Community Services
		172	Motion Picture Production
		173	Movie Theater
		174	Radio, Television and Related Services
		175	Library and Museum
		176	Amusement and Recreation
		177	Repair, Not Elsewhere Classified
		178	Personal Services
026	Unclassified (180)	180	Unclassified