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An extended Input–Output framework for evaluating industrial sectors and provincial-level water consumption in Indonesia

Geetha Mohan [a,b,*], Saroj Kumar Chapagain [a,**], Kensuke Fukushi [a,b], Seksan Papong [c], I.Made Sudarma [d], Andi Besse Rimba [a,b], Takahiro Osawa [d]

[a] *United Nations University Institute for the Advanced Study of Sustainability, Shibuya, Tokyo, 150-8925, Japan*
[b] *The University of Tokyo Institute for Future Initiatives, Bunkyo-ku, Tokyo, 113-0033, Japan*
[c] *National Science and Technology Development Agency, Pathum Thani, 12120, Thailand*
[d] *Centre of Environmental Research, Udayana University, PB Sudirman, Denpasar, Bali, Indonesia*

A R T I C L E I N F O

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A B S T R A C T

This paper provides an extended input–output (IO) model of sectoral water consumption for Bali, a province located in Indonesia that is a well-known global tourist destination. Currently, the province is experiencing water shortages, which leads to a burden and heavy competition in water usage among the various economic sectors. We developed a method for determining which industrial/economic sectors directly and indirectly consume the most substantial quantities of water and to what extent available water resources can become a restrictive factor in the development of leading economic sectors. We also used another method, backward and forward linkage indices, to identify the key sectors influencing water consumption. The results confirm that the agriculture sectors, including other food crops, non-food crops, and rice, consume the highest portion of total water consumption. However, indirect water consumption appears to comprise a vital share of total water resources. These sectors—including the livestock industry; food, beverage, tobacco, and coffee industries; the timber industry; wood products, crafts and minerals industry; trading; construction; and other processing industries—have the highest indirect consumption. Our model for direct and indirect water consumption is a useful tool for water and economic planning policymakers for devising water-saving policies and expanding the provincial economy.

1. Introduction

Water plays a critical role in society and is a vital driving force behind economic growth. Along with other regions of the world, the Asia-Pacific region is confronting major freshwater water resource glitches due to the increasing population, rapid urbanization, and

Abbreviations: FAO, Food and Agriculture Organisation; IO, input–output; GRDP, gross regional domestic product; PDAM, The Perusahaan Daerah Air Minum; AIIO, Asian international IO table; *wcm*, water consumption multiplier; *iwc*, indirect water consumption; ICSSR, The Indonesia Climate Change Sectoral Roadmap; IDR, Indonesian Rupiah.

* Corresponding author. United Nations University Institute for the Advanced Study of Sustainability, 5-53-70 Jingumae, Shibuya-ku, Tokyo, 150-8925, Japan.
** Corresponding author.
E-mail addresses: Geetha.mohan@unu.edu (G. Mohan), Saroj@unu.edu (S.K. Chapagain).

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economic development [21,67]. The region faces inconsistency of demand to enhance agriculture, industrial, and energy production with a diminishing per capita water availability [2]. Indonesia is among the Asian nations that are significantly affected by droughts and floods in various administrative provinces. Currently, the country is facing intensifying freshwater supply issues, predominantly on Java and Sumatra Islands, where the demand for freshwater is the highest. The problems related to freshwater shortages are population growth, industrialization, overuse, urbanization, and the insufficient supply of water in some provinces (e.g., Bali) and regions [59]. The island of Bali, a well-known tourist destination, is one of 34 Indonesian provinces covering a geographical area of 5, 636 kilometers (km^2). According to Bali province statistics, the economy has become reliant on the tourism sector, which is renowned for its overuse of water resources. While agriculture is still the primary user of water, the water use of domestic households and the tourism industry, as well as other industrial water users, is currently increasing. The Balinese water supply is restricted because of massive stretches of coastland with sensitive and restricted groundwater potential compared to the small size of the island and its dense population [4,19]. The water supply is considered critical to the high population density and tourism infrastructure and a 70% upsurge in water consumption is projected in all regencies, including South Bali of Denpasar, Badung, and others (see Fig. 1) by 2025 [3,31,57].

Under these challenges, water is progressively becoming a priority policy issue on an international, national, and regional level. In 2012, the fourth edition of the World Water Report [67] recognized the importance of “robust governance mechanisms are necessary to protect water resource and ensure sustainable development and equitable distribution of water-derived benefits” (p. 2). Evaluating the demand of the various sectors requires a comprehensive understanding of the issues. This paper will address some of these issues, focusing on the interrelationship between the consumption of water and the production structure in Bali.

This paper is organized as follows. The first section provides a brief introduction, states the importance of the economic situation and water resource in Bali province and water consumption of multiple sectors, and reviews the literature on water extended IO model, followed by the objectives. Sections 2 and 3 present the methodological framework including the water IO framework, water consumption multipliers, and backward and forward linkages, followed by a description of the regional economic and water data. Section 4 presents the results and discussion. Section 5 presents the limitations of the study. Finally, the policy implications and future directions are presented in the last section.

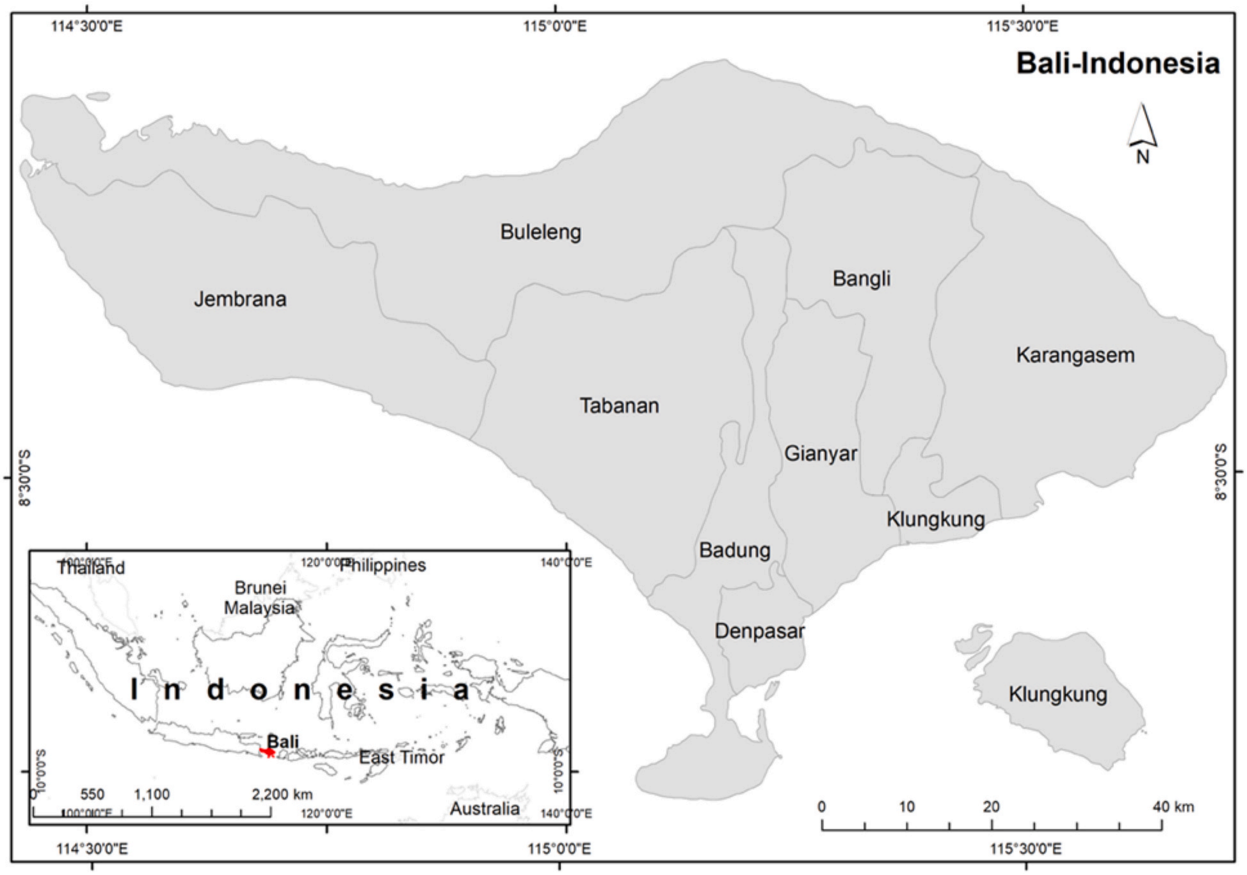

Fig. 1. Map of island of bali province and the regencies.
Source: Badan informasi geospasial (BIG).

1.1. Importance of the economic situation and water resources in bali

The province of Bali has been historically dominated by the agricultural sector, which is a major economic driver for the province. In 1969, the agrarian sector contributed 61.21% of Bali's gross regional domestic product (GRDP) [7,8,10,18,66]. Fig. 2 illustrates that, as of 2018, the contribution of the primary sector, agriculture, to the GRDP decreased to 13.78%. A major recent development in the Balinese economy has been the expansion of the trade and service sectors. The tourism sector (accommodation & food service activities) has increased from contributing 9.59% in 1969 to 18.20% in 2005 and 23.33% in 2018, swiftly taking over the Balinese economy [66].

Predominantly, these distributions clearly demonstrate that the tourism sector has become a driving force in Bali's economic development and a significant economic boost for Bali province. The transportation industry, crucial for scaling up tourism, accounted for 7.39% in 2010 and 9.74% in 2018, followed by the construction industry, which reports increasing from 4.03% in 2005 to 9.39% in 2018. The trade, restaurants, and hotels sector makes a significant contribution not only to the economy but also to employment, representing 31.69% (760,093 jobs) in 2017 [7] (BPS, 2018). The dominant tourism-associated industries have been recognized as placing a considerable burden on water supplies and competing with local users as well as surpassing agriculture in terms of its contribution to the GRDP [4,23,32,46]. This creates an imbalance between sectors due to the higher water consumption of the tourism sector, which reportedly consumes 65% of all local water resources [13].

1.1.1. Freshwater resources by regency in bali

Water is important to the development of economic activity and vital for sustaining life and livelihoods, as well as having religious and cultural significance. The province of Bali's annual rainfall differs because of climatological changes and is less than 1,500 mm in the coastal zone and 3,000 mm in the mountainous areas [53] (Siska, 2018). The main freshwater resources for the Bali province are groundwater (40.0%), followed by springs (28.7%), rivers (25.0%), and others (5.3%). The regencies of Denpasar and Badung have 44.5% of all freshwater resources, while Buleleng, Tabanan, Gianyar, and Klungkung regencies have 40.3%. The remaining regencies of Jembrana, Bangli, and Karangasem comprises 15.2% of all freshwater resources (see Table 1). As we can see, the sources of freshwater resources are unevenly distributed across the province of Bali. According to the Ministry of Public Works (2015), several rivers in the province of Bali are perennial rivers that account for 41.0%, some do not flow during the dry season, and only 21.0% of rivers flow during the wet season (cited in Siska, 2018 [53]) [40]. However, the regencies of Denpasar, Gianyar, and Jembrana, followed by Buleleng and Badung, consume more groundwater resources, which may be the reason for maintaining the water demand for the tourism sector for daily activities, including swimming pools and gardens.

According to the Food and Agriculture Organisation (FAO) (2003), Bali's water supply is compromised because of massive areas of coastland with sensitive and limited groundwater potential relative to the small size of the Bali island and its dense population (cited in Ref. [55] Strauβ, 2011) [19]. In addition, a limited water supply occurred during the months of July and October due to because of shortage of rainfall that creates water stress and intensify the water demand between the local communities and economic sectors. In this way, the water allocation problems caused by the high rate of population density and as well as the competition among dominant economic sectors of agriculture, tourism, and other sectors would lead to severe problems with the water supply [4,55]. Therefore, it is indispensable to seek new options for managing the available water resources in a sustainable manner.

1.1.2. Water use for different sectors

The composition of water use in Bali has increased 1.1% (0.02 billion cubic meters (m^3)) as a whole; however, the distribution of water use between agriculture, domestic users, and the tourism industry changed from 92%, 7%, and 1%, respectively, in 1994 to 88%, 10%, and 2%, respectively, in 2013. Water use for agriculture exhibited a fluctuating trend between 1994 and 2014; decreasing from

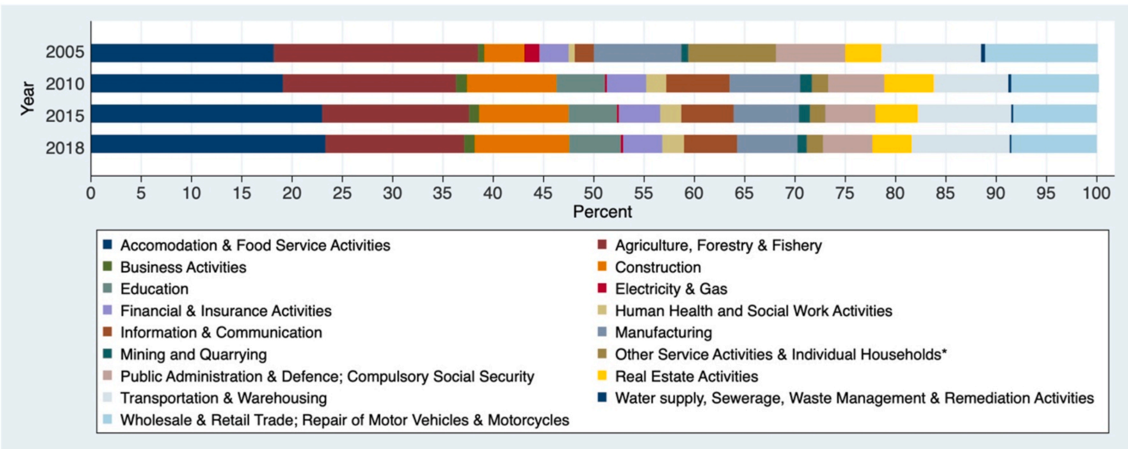

Fig. 2. Distribution of gross regional domestic product across major economic sectors in the Bali province in 2005, 2010, 2015, and 2018.

Table 1
Freshwater resources by regency in Bali, 2015 (million m^3).

Regency	River	Lake	Spring	Groundwater	Others[a]	Total	Population (000 number)
Jembrana	1,711		182	10,482		12,375 (7.3)	271.60
Tabanan	3,168	1,499	13,606			18,273 (10.9)	435.90
Badung	22,763		2,701	9,305	701	35,469 (21.1)	616.40
Gianyar	890		4,158	11,277		16,324 (9.7)	495.10
Klungkung			6,955	1,484	5,889	14,328 (8.5)	175.70
Bangli			4,177			4,177 (2.5)	222.60
Karangasem			7,156	1,911		9,067 (5.4)	408.70
Buleleng			9,445	9,445		18,890 (11.2)	646.20
Denpasar	13,628			23,510	2,325	39,463 (23.4)	880.60
Bali	42,159 (25.0)	1,499 (0.9)	48,379 (28.7)	67,414 (40.0)	8,915 (5.3)	168,366 (100.0)	4152.80

Source: Statistics of Bali Province (BPS), 2015 [9].
Note: Figures in the parentheses represent percentages.
[a] Others could be deep wells supplying Perusahaan Daerah Air Minum raw water.

1994-2003 and then increasing between 2003-2014 due to growth in rice production [53].

The Perusahaan Daerah Air Minum (PDAM) is a local government-owned water utility whose responsibility it is to provide clean water supply to various sectors except the agricultural sector (Appendix-1). The rising population density caused an increase in water consumption by households (i.e., the domestic sector), from 67.7% in 2009 to 75.0% in 2015, followed by trade companies (from 8.0% in 2009 to 11.2% in 2019), which includes multiple services such as star and non-hotels, restaurants, and showrooms, etc. The water use by the manufacturing sector includes food and beverage and textile, chemical, and as shown in Fig. 3, other industries declined from 5.7% in 2009 to 4.7% in 2015. Earlier studies (e.g., Cole, 2012; Suriyani, 2015; Trisnawati, 2012) have reported that tourism consumes 65% of all local water resources, which creates conflict between the hotel industry and local communities [13,56,58]. According to Tourism Concern (2012), the changes in water supply distribution in favor of tourism raise questions regarding water quality and equity between the various economic sectors, trade companies, and domestic users [42]. Sometimes, conflicts arise between farmers and PDAM and local communities over clean water. Siska et al. (2018) argued that there is a misunderstanding between water users on the level of water availability and allocation among sectors, predominantly as a result of the recent rapid development in tourism [53]. Therefore, by addressing these issues and the water challenges between the different sectors in the province of Bali, this study will determine precisely which sectors consume more water, both directly and indirectly, by using an extended IO

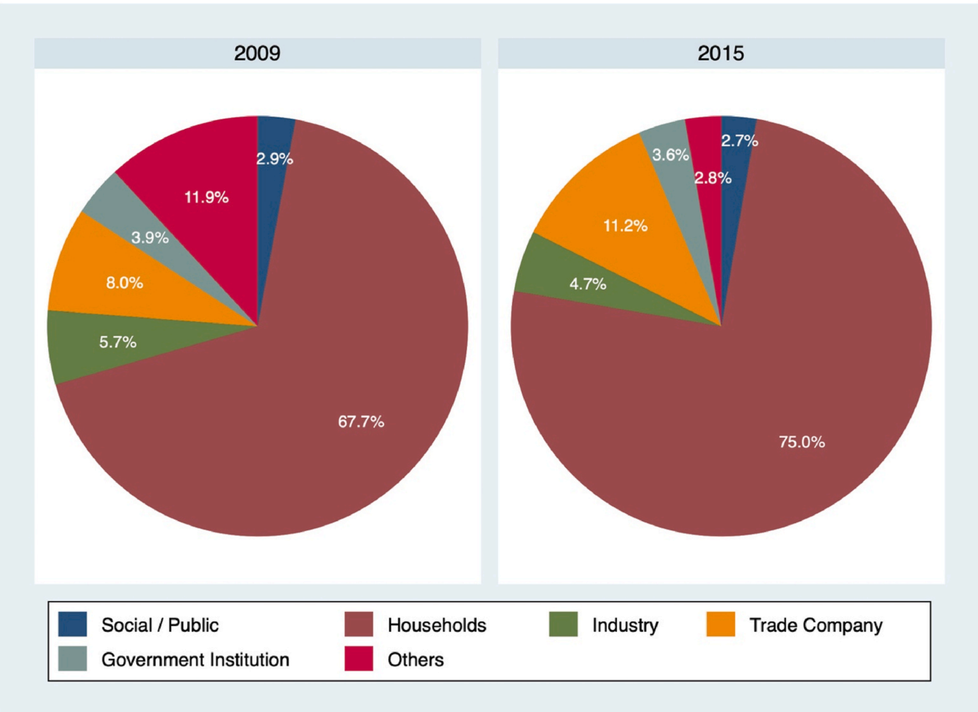

Fig. 3. Distribution of water supply by Perusahaan Daerah Air Minum to sectors
Source: Badan Pusat Statistik Provinsi Bali, 2009, 2015 [9].

framework, so that the findings can provide better solutions for the management of water resources.

1.2. Review of literature

The Leontief IO model is a valuable tool for structural analysis and is widely used in the global academic community. Several studies have used this tool to analyze economic structures and their physical impact on the environment, such as energy consumption, environmental pollution, and water pollution. The application of the IO model to environmental interactions, the cost of economic industries, and final demand categories were first introduced in 1966 by Cumberland (cited in Ref. [62]) [70]. Later, in 1970, Leontief extended the IO model to analyze environmental issues by adding new rows or corresponding columns to accommodate new production inputs or outputs [36]. Proops (1977) used the extended IO model to set up a range of indicators of both direct and indirect energy use [47]. Several researchers have used an extended IO model to study energy consumption and atmospheric pollutant-related issues [1,15,20,33,41,51,52,71].

From an economic perspective, the application of IO analysis to water resources has received limited attention; studies that use the IO framework are even fewer. In earlier studies, Harris and Rea (1984) (cited in Ref. [43]) conducted a water allocation study in the United States (US) [25], and in 1992, Sanchez-Choliz et al. (cited in Ref. [61]) applied the IO methodology to Spain [50]. Only a few studies have assessed the effects of economic production structures and domestic demand on natural water resources, especially in water threatened regions and countries [6,11,16,24,28,34,35,63–65,68,69]. Using an environmental (water) extended IO (EEIO) framework, Hristov (2016) concluded that because of the seasonal and spatial distribution of water resources in the Western Balkan region, the sustainable management of water resources is crucial in Macedonia [77]. The EEIO analysis supports data on environmental, economic, and water policies by quantifying how the demand for goods and services leads to resource use in the economy [74,76]. Moreover, the EEIO framework provides a high resolution of sectors and structural economic composition, which makes it a useful tool for supply chain impact assessment [78]. Recently, several IO studies have been conducted about water resources in China [11,14,24,28,38]. For instance, Wang et al. (2009) developed a method to identify the relationship between production activities and the related water consumption in Zhangya City, an arid area of northwestern China, which is categorized as a water shortage area [64]. However, the situation in China is not the same as that in other developing Asian nations. Ono et al. (2017) developed a water consumption inventory database that focused on investigating Asian water use with an IO framework [44]. The data inventory is quite useful for countries like Indonesia for assessing the relationship between economic activity and water consumption. Bogra et al. (2016) described a water-withdrawal IO model by combining data about direct water withdrawal attained from various sources using a 2003–2004 economic IO table [5]. Furthermore, they estimated the direct and indirect water withdrawal of all industrial sectors in India. Pavisorn et al. (2018) used an IO model to assess the relationship between water use and Thailand's economic structure [45]. Čegar (2020) constructed a water extended IO model and empirically applied it to his study using the indicators of direct, indirect, and quantified cumulative water intensity of production sectors, including indirect water-use multipliers, in the Croatian economy [79].

With regard to Indonesia, most studies using an IO framework focus on structural changes in economic industries and trade [26,72,73]. For example, Dwiatmoko et al. (2019) used IO analysis to investigate the effect of railway development on the Indonesian national economy [17]. Moreover, James and Fujita (2000) used IO tables to estimate the employment effects of manufactured exports in two sub-periods [30]. Budy Resosudarmo (2003) used IO analysis to conduct research to identify policies to solve river water pollution in Indonesia [49]. With this background, we found that no study used IO tables to examine the province of Bali or other Indonesian provinces. Moreover, the current water resources situation in Bali province [53,55], particularly the higher water-use competition among industrial sectors (e.g., the agriculture and tourism sectors), leads to conflicts among stakeholders. Therefore, to fill the gaps mentioned above, this study develops a water IO table for Bali province to explore the interrelationship between the economic sectors that consume the highest amount of water both directly and indirectly. This study is the first attempt to use the water extended IO method to quantify how demand for goods and services in these sectors leads to water use in the Bali provincial economy; it is also the first study about Indonesia and other developing nations in Asia except China. In addition, this study has significant practical implications for Asian countries and others that have similar water competition situations.

The foremost objective of this study is to examine the relationship between the various economic sectors and their physical relationship with water consumption. The appropriate method for analyzing the direct and indirect, as well as the intersectoral water relationships in an economy, is the extended Leontief IO model [39], while extending the model for water use [61]. Second, this study also attempts to determine the sectors that consume the highest amount of water both directly and indirectly. To explore the key sectors that have the most significant effect on the entire water consumption process in terms of both purchases and sales in the economy, this study employs backward and forward linkages [70]. The conclusions of this study will elucidate better solutions to facilitate the design of sustainable water-use policies at the provincial level and address the intensifying competition for water among various economic sectors.

2. Methodology

To achieve the sustainable use of water resources, the construction of an IO table is indubitably important for examining the relationship between economic sectors and water consumption. In this paper, we adopt a traditional Leontief IO model and extend it in terms of water consumption.

2.1. Conventional IO production model

The fundamental Leontief IO model is normally constructed from observed economic data for a country, region, or province and a specific time period. IO analysis is concerned with, according to Miller and Blair (2009), "the activity of a group of industrial sectors that both produce of goods (outputs) and consume goods from other industrial sectors (inputs) in the process of producing each industry's own output" [39, p. 2].

In Table 2, the extra column, categorized as *Final Demand*, comprises of household and government consumption, capital investments, and net exports of goods and services, which represents the sales by each sector to final markets to use for production. The additional row, labeled *Value Added*, accounts for other (non-industrial) inputs to production, such as labor, depreciation of capital, indirect business taxes, and imports [39].

The IO model consists of a set of linear equations. The basic equation in the Leontief model determines that the production of an economy depends on intersectoral relations and final demand.

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

where x_{ij} represents the values of the transactions from each sector i to sector j and d_i denotes the final demand for goods for each sector.

This equation can be rewritten to incorporate the technical coefficients of production (a_{ij}), which are described as the purchases that sector j makes from sector i per total effective production unit of sector j, which represents the direct input required by sector j.

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

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

In matrix notation, for the entire economy, it becomes:

$$x = Ax + d \tag{4}$$

To solve for x, we obtain the total production delivered to final demand:

$$x = (I - A)^{-1} d \tag{5}$$

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

For further expression of Equation (5), the production of sector i can be specified as follows:

$$x_i = \sum_{j=1}^{n} \beta_{ij} d_i \tag{6}$$

where β_{ij} are the elements in the Leontief inverse matrix $(I - A)^{-1}$ describes the increase in production generated by sector i if the demand of sector j increases by one unit. The column sums of this matrix express the total (direct and indirect) requirements of a sector to meet its final demand. The diagonal elements in the matrix are the direct effect and the column sum of the off-diagonal elements equals the indirect effect.

Table 2
IO transaction table of production.

Producer Sector	Consumer Sector				*Final demand*			Total Output
	Sector-1	Sector-2	… …. .	Sector-n	Consumption	Investment	Exports	
Sector-1 Sector-2 : : Sector-n	X_{ij}				D_i			X_i
Value added	V_j				V_j^D			V_i
Imports	M_j				M_j^D			M_i
Total Inputs	X_j				D_j			

Source: Miller and Blair, 2009 [39].
Note: Capital letters in the table specify matrix notation.

2.2. Water Input–Output model

2.2.1. The extended IO model of water consumption

As we elucidated in an earlier section, the extension of the conventional method is done in terms of water consumption. It is completed by adding an additional row (ω) in which physical data on each sector's water use is considered as a production factor. This model defines total water consumption and differentiates between direct and indirect water consumption. These concepts can be presented in the model, which allows us to formulate a matrix of intersectoral water relationships and analyze the relative importance of direct and indirect water consumption [61].

Hereafter, production vector (x_j) data are expressed in monetary units. The indicator of total direct consumption per unit produced (ω_j^{∂}) can be defined by dividing the water consumed directly by each sector (ω_j) with total input to that sector (x_j). This expression, as a column vector, is defined as follows.

$$\omega_j^{\partial} = \frac{\omega_j}{x_j} \tag{7}$$

In matrix notation, as earlier, it will be denoted as:

$$\omega^{\partial} = \omega \widehat{x}^{-1} \tag{8}$$

where $\widehat{x}$ indicates a diagonal matrix with the elements of x on the leading diagonal.

To differentiate between direct and indirect effects, Equation (8) can be rewritten in terms of the total water consumption multiplier by simply multiplying the direct water consumption coefficient (ω_j^{∂}) by the quantity produced by each sector.

$$\omega^{\partial} x = \omega \tag{9}$$

From Equation (5), the production vector x can be expressed as open Leontief model to obtain the total water consumption (ω) of the economy in terms of its own demand.

$$\omega = \widehat{\omega}^{\partial}(I - A)^{-1} d \tag{10}$$

$$\omega^{t\partial} = \omega^{\partial}(I - A)^{-1} \tag{11}$$

The expression $\omega^{\partial}(I - A)^{-1}$ is an indicator of total water consumption ($\omega^{t\partial}$). Further, it is a row vector that defines the total amount of water that the economy will both directly and indirectly consume if there are any changes in demand by one unit of any given sector. We continued our analysis by further adopting Velazquez's (2006) water consumption model [61] to Proops' model of energy use (1988) [47].

$$\omega^{t\partial} = \omega^{\partial} + \omega^{\partial} A + \omega^{\partial} A^2 + \ldots + \omega^{\partial} A^n + \ldots. \tag{12}$$

From the expansion of Equation (11), the direct water consumption needed to sustain production by the economy can be separated from the indirect [22,68]. In Equation (12), where ω^{∂} is the direct water requirement that is denoted by one unit of output from all sectors, I. The expression $\omega^{\partial} A$ is the water needed to let enable the production of $A.I.$ and is called the "first-round" indirect water consumption, and $\omega^{\partial} A^n$ is considered to be nth-round indirect water consumption, or the water required to produce the goods $A^n.I.$ Evidently, the sum of the entire round of consumption is called total indirect water consumption [64].

2.2.2. The water consumption multiplier (**wcm**)

As specified earlier, total water consumption can be separated into direct and indirect effects. To capture the indirect effect, we must first consider the "drag effect." The Leontief model accounts for the effect whereby the evolution of a given sector can "drag" total economic production. In terms of water consumption, the "drag" effect is measured by dividing the earlier defined indicator of total consumption ($\omega^{t\partial}$) by the indicator of total direct consumption (ω^{∂}), i.e., the water consumption multiplier (*wcm*) [61].

$$wcm_j = (I - A)^{-1} = \frac{\omega_j^{t\partial}}{\omega_j^{\partial}} \tag{13}$$

The water consumption multiplier (*wcm*) defines the total quantity of water consumed by the entire economy per unit of water used directly to satisfy the demand of a given sector *j*. In addition, an indicator of indirect water consumption (*iwc*) per currency unit produced can be attained by simply subtracting unity from *wcm*. This indicator also yields an estimate of the quantity of water used indirectly by sector *j* for each unit of water consumed directly to fulfill the demand of that sector [64].

$$iwc_j = wcm_j - 1 = \frac{\omega_j^{t\partial}}{\omega_j^{\partial}} - 1 = (I - A)^{-1} - I \tag{14}$$

2.2.3. The matrix of intersectoral water relationships and the associated matrices

From Equation (11), we can specify a row vector in which each element defines the total water consumption of any given sector output changes by one unit. By substituting the form of ω^{∂} and subtracting direct water consumption from total water consumption, a matrix for the intersectoral water relationship ($\omega^{iwr\partial}$) may be obtained [64].

$$\omega^{iwr\partial} = \widehat{\omega}^{\partial}\left[(I - A)^{-1} - I\right] \tag{15}$$

where '$\wedge$' states that the vector's element must be assigned alongside the diagonal of the matrix. The new elements of $\omega_{ij}^{iwr\partial}$ denote the additional quantity of water that would be consumed by the entire economy for each unit of additional output of the respective sector *j*. The sum of all elements of column *j* expresses the indirect water requirements per unit of output of sector *j*. This matrix is like traditional IO technical coefficients in that it is able to be converted into a matrix of water transaction coefficients (ψ_{ij}^{ω}).

$$\psi_{ij}^{\omega} = \frac{\omega_{ij}^{iwr\partial}}{\omega_j^{\partial}} \tag{16}$$

The element ψ_{ij}^{ω} indicates the additional quantity of water that sector *i* will consume if the final demand for water by sector *j* increases by one unit. The column sum of sector *j* must be equal to the indirect water consumption (*iwc*) of the respective sector. Therefore, this new matrix reveals the intersectoral dependence between one sector and other sectors regarding water resources. This is relatively important to the study, in which a detailed evaluation is demonstrated.

2.2.4. Limitations of EEIO methods

The following are some salient limitations of EEIO methods [33,79]:

- The accurate assessment of environmental impact and associating these impacts with the sectors is challenging.
- IO tables are mostly not available in many nations and are published in considerably long intervals.
- IO tables may not capture all activities in the economy, especially in low-income nations.
- The most critical assumption of EEIO is homogeneity or the assumption that each sector in the economy produces a single, homogeneous good or service.

All these limitations are mostly related to the accuracy and reliability of open static IO models as simulation and predictive tools. Compared with that of other analytical tools and different methodologies, an EEIO analysis of the capacities and capabilities of production systems and economic structures are unique and even irreplaceable [79].

2.3. Indices of backward and forward linkages

We have developed the water IO model, including recognizing the water transaction coefficients, the water consumption indicators, and intersectoral water relationships in earlier sections. Earlier studies on crucial sectors and linkages are frequently expressed entirely in monetary terms. The identification of key sectors is considered useful for economic planning, especially in developing nations. The concept of forward and backward inter-industry linkages was introduced by Rasmussen to measure structural interdependence [48,75,82,85]. Given today's environmental problems, more attention is being paid to studying economic structures in terms of resource use and water availability. Therefore, to identify the key sectors and linkages related to environmental impact, assessing the increasing water demand and ecosystem degradation is more useful. The classification of environmentally significant sectors and linkages should differ from that attained in a purely economic analysis [83,84]. Now, backward and forward linkages, which play an essential role in investigating the sectors that have the greatest influence on the entire water consumption process via sales and purchases in the economy, will be discussed [39,70]. Several studies on inter-industry linkages have been performed using different methods, as can be seen from in Chenery et al. (1958), Duarte et al. (2002), and Velazquez (2004) [12,16,60]. However, in this study, we applied Rasmussan's (1956) indicators for linkage analysis [48].

Backward linkage ($BL_j^{\prime}$) shows how much sector *j* affects the other sectors over purchases concerning water consumption and it can be defined as the column sum of the Leontief inverse matrix $(I - A)^{-1}$. Forward linkage ($FL_i^{\prime}$) indicates how much sector *i* influences others through its sales and is measured as the row sum of the Leontief inverse $(I - A)^{-1}$ from a supply-side viewpoint [10].

$$BL_j^{\prime} = \widehat{w}^{\partial} \sum_{i=1}^{n} a_{ij} \tag{17}$$

where (BL_j) is the backward linkage, explained as the column sum of the Leontief inverse matrix $(I - A)^{-1}$ from the water IO model; a_{ij} represents each of the elements in the matrix.

$$FL_i^{\prime} = \widehat{w}^{\partial} \sum_{j=1}^{n} \overrightarrow{a}_{ij} \tag{18}$$

where (FL_i') is the forward linkage, described as the row sum of the Leontief inverse matrix $(I-A)^{-1}$ from the water IO model; $\overrightarrow{a}_{ij}$ represents each of the elements in the matrix.

These linkages can be defined as indices below:

$$\Re_{BL} = \frac{\frac{1}{n}\mathscr{b}_j}{\frac{1}{n^2}\sum_{j=1}^{n}\mathscr{b}_j} = \frac{\mathscr{b}_j}{\frac{1}{n}\sum_{j=1}^{n}\mathscr{b}_j} \tag{19}$$

$$\Re_{FL} = \frac{\frac{1}{n}\mathfrak{f}_i}{\frac{1}{n^2}\sum_{i=1}^{n}\mathfrak{f}_i} = \frac{\mathfrak{f}_i}{\frac{1}{n}\sum_{i=1}^{n}\mathfrak{f}_i} \tag{20}$$

If $\Re_{BL}$ is greater than 1, a one-unit change in final demand in sector j will result in an above-average increase in the water consumption of all sectors in the entire economy. By contrast, if $\Re_{FL}$is greater than 1, a unit change in all sectors' final demand will lead to an above-average increase in the water consumption of only sector i [12]. Generally, if the backward and/or forward linkage indices are greater than 1, we can say that these sectors are the key/leading sectors in terms of water consumption. In this paper, such a method is taken one step further and applied to the environmentally extended IO model of the Balinese economy, which comprises 25 sectors. The forward and backward linkages are analyzed to demonstrate the direct and indirect effects of investing in particular sectors of the Balinese economy.

This study provides new insights to its subsequent application of the derived forward and backward linkage coefficients to identify the most "dominant" sectors. This enables the Balinese economy to stimulate economic development yet simultaneously produce minimal environmental effects across the provincial economy. Moreover, it is extremely beneficial for analyzing the economy-wide environmental impact of government investment programs during times of crisis [75].

Table 3
Sector-wise water consumption indicators.

S. No.	Sector	Direct water consumption ($10^6 m^3$)	Total water consumption ($10^6 m^3$)	Sector output (10^9 IDR)	Direct water consumption per unit of output (ω^{∂}) ($m^3/10^6$ IDR)	Total water consumption per unit of output ($\omega^{t\partial}$) ($m^3/10^6$ IDR)
1	Rice	739.3	894.0	1,174	629.6	761.4
2	Maize	140.0	165.1	180	778.1	917.2
3	Other food crops	2,496.7	2,764.8	3,468	720.0	797.3
4	Plantation or non-food crops	837.3	1,244.2	1,183	707.7	1051.5
5	Livestock	10.5	13.7	6,963	1.5	2.0
6	Forestry and its products	20.3	40.5	3	7669.1	15333.8
7	Fishery	6.8	10.5	2,734	2.5	3.8
8	Padas stone and other minerals	0.9	1.9	431	2.1	4.4
9	Food, beverage, tobacco, and coffee industries	45.0	52.1	2,883	15.6	18.1
10	Textile, apparel, and leather goods industries	30.5	51.4	4,573	6.7	11.2
11	Timber industry and wood products	1.6	3.6	2,066	0.8	1.7
12	Paper industry and paper and cardboard goods	5.5	9.9	154	35.8	64.2
13	Fuel and chemical industry, rubber, and plastics	6.3	10.1	1,309	4.8	7.7
14	Crafts and minerals industry	0.0	0.1	28	1.2	2.2
15	Other building materials (non-metal mineral goods) industry	0.2	0.4	94	2.1	3.8
16	Car body industry and transportation equipment	0.1	0.3	363	0.4	0.8
17	Jewelry industry	0.0	0.0	24	0.2	0.3
18	Other processing industries	0.0	0.1	216	0.2	0.6
19	Electricity	0.2	0.3	1,232	0.2	0.2
20	Construction	7.7	13.7	5,451	1.4	2.5
21	Trading	24.2	32.7	6,925	3.5	4.7
22	Hotels and restaurants	259.6	300.2	15,452	16.8	19.4
23	Transport and other transport services	41.2	57.9	7,491	5.5	7.7
24	Communications, post, and Giro	2.3	3.1	1,435	1.6	2.2
25	Financial, public, community, cultural and entertainment, and other services	31.2	38.7	12,495	2.5	3.1

Note: Direct water consumption estimated for Bali region were taken from Ono et al.'s study [44]; the sectoral output (monetary value) data were gathered from the Bali input–output table created by the Badan Pusat Statistik Provinsi (BPS) office, Bali province. IDR is Indonesian Rupiah.

3. Data sources

The dataset in this paper primarily comprises two types: a regional IO table that facilitates investigating the flows of goods and services among producers and consumers and the interrelationships between all economic sectors. The water data contain direct water consumption and the water consumption coefficients, i.e., both direct and indirect. The quantity of freshwater consumption to produce a unit of output of sales or purchases in all economic sectors.

3.1. Regional IO economic data

Recent research has paid more attention to analyzing the regional economic impact and intersectoral relationships within a region [37,54,68]. In our analysis, the regional IO tables (in monetary value units) for Bali province are for the year 2007 from the *Badan Pusat Statistik, Provinsi Bali* (Statistics of Bali Province) [10]. The IO table classification is based on 54 sectors; however, mining and basic metal industry and other metal goods sectors were excluded because of a lack of data. The IO table structure includes the flow of intermediate consumption of production sectors, final consumption and exports, and the use of imports. To make the comprehensive dataset reliable, a few changes to the IO table were needed due to restrictions in water consumption data. As a result, we combined 25 of the 52 sectors into aggregated sectors and developed a 2007 table for Bali that represents a 25 sector by 25 sector IO table, whose grouping of economic sectors is constant with our division of 25 water-use classifications (see Appendix 2).

3.2. Water data

Sector-wise water consumption data are not available for the province of Bali, Indonesia. The water data in this paper were taken from the water consumption inventory database [44], which covers all goods and services in Asia. Predominantly, the water consumption associated with the economic sectors in nine Asian countries, including Indonesia, uses the Asian international IO table (AIIO). This water data include rainwater, surface water, and groundwater, but not greywater. We estimated the direct water consumption for each sector using the direct water consumption data from Indonesia, except for a few sectors related to services. To obtain data for these sectors, we determined direct water consumption by sector by referencing the volume of freshwater drawn from sources of water by a given sector [27].

4. Results and discussion

Water consumption in the province of Bali, Indonesia has recently received much attention, due to developing water scarcity in the region and conflicts between the tourism and agriculture sectors. To understand the situation with water resources and analyze Bali's water consumption patterns, we need to learn which sectors consume more water than others and which key sectors have a greater influence on the entire water consumption process. In this section, we present and discuss the results obtained from the analysis.

Table 4
Distribution of direct and indirect water consumption to total water consumption and water consumption multipliers.

S. No.	Sectors	$\omega^{\partial}/\omega^{t\partial}$(%)	$(\omega^{t\partial}-\omega^{\partial})/\omega^{t\partial}$ (%)	*wcm*	*iwc*
1	Rice	0.83	0.17	1.09	0.09
2	Maize	0.85	0.15	1.23	0.23
3	Other food crops	0.90	0.10	1.16	0.16
4	Plantation or non-food crops	0.67	0.33	1.33	0.33
5	Livestock	0.76	0.24	39.35	38.35
6	Forestry and its products	0.50	0.50	1.10	0.10
7	Fishery	0.65	0.35	3.58	2.58
8	Padas stone and other minerals	0.48	0.52	3.02	2.02
9	Food, beverage, tobacco, and coffee industries	0.86	0.14	28.58	27.58
10	Textile, apparel, and leather goods industries	0.59	0.41	7.72	6.72
11	Timber industry and wood products	0.46	0.54	23.90	22.90
12	Paper industry and paper and cardboard goods	0.56	0.44	2.13	1.13
13	Fuel and chemical industry, rubber, and plastics	0.62	0.38	64.12	63.12
14	Crafts and minerals industry	0.52	0.48	26.86	25.86
15	Other building materials (e.g., non-metal mineral goods) industry	0.55	0.45	4.50	3.50
16	Car body industry and transportation equipment	0.46	0.54	21.05	20.05
17	Jewelry industry	0.66	0.34	12.07	11.07
18	Other processing industries	0.31	0.69	107.10	106.10
19	Electricity	0.62	0.38	8.74	7.74
20	Construction	0.57	0.43	7.94	6.94
21	Trading	0.74	0.26	2.90	1.90
22	Hotels and restaurants	0.87	0.13	4.77	3.77
23	Transport and other transport services	0.71	0.29	2.78	1.78
24	Communications, post, and Giro	0.73	0.27	3.15	2.15
25	Financial, public, community, cultural and entertainment, and other services	0.81	0.19	2.85	1.85

Note: *wcm*-water consumption multiplier; *iwc*-indicator of indirect water consumption.

Table 5
The water transaction coefficients for 25 sectors of the Bali province.

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
1	0.1	0.0	0.0	0.0	14.5	0.0	0.9	0.0	18.0	0.1	0.2	0.0	0.2	0.2	0.2	0.4	0.5	7.1	0.8	0.1	0.1	0.8	0.2	0.2	0.1
2	0.0	0.2	0.0	0.0	0.4	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.1	0.0	0.0	0.1	0.0	0.0	0.0
3	0.0	0.0	0.2	0.0	5.9	0.0	0.1	0.0	1.8	0.2	0.3	0.0	0.1	0.5	0.1	0.8	1.1	4.7	1.6	0.2	0.2	1.7	0.4	0.3	0.3
4	0.0	0.0	0.0	0.3	14.2	0.0	0.6	1.0	7.4	5.2	8.1	0.4	61.8	1.1	0.7	15.1	2.8	75.9	2.3	2.4	1.1	0.9	0.3	0.5	0.9
5	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	0.0	0.0	0.0	0.0	0.2	0.1	0.0	0.3	0.0	0.1	11.7	0.0	0.1	21.9	1.3	0.1	0.7	2.1	0.1	2.1	0.0	0.0	0.0	0.1	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.5	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
8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.5	0.2	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.1	0.0	0.0	0.0
10	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.1	0.0	0.0	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.7	0.0	0.0	0.0	0.0	0.0	3.2	0.1	0.0	0.0	0.0	0.0	0.1	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.5	0.0	0.0	0.4	0.1	1.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0
14	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	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	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	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16	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	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	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	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
18	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	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	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	0.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.1	0.1	0.1	0.8	0.0	0.0	0.0	0.1	0.0
21	0.0	0.0	0.0	0.0	0.6	0.0	0.1	0.0	0.0	0.1	0.4	0.0	0.1	0.3	0.2	0.5	1.9	1.5	0.1	0.3	0.2	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.3	0.1	0.5	0.7	2.7	1.1	0.1	0.1	0.2	0.3	0.2	0.2
23	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.1	0.2	0.0	0.1	0.2	0.1	0.5	1.8	1.6	0.5	0.2	0.0	0.0	0.4	0.1	0.0
24	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	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.0
25	0.0	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.3	0.0	0.1	0.2	0.1	0.4	0.6	1.8	0.6	0.2	0.1	0.0	0.0	0.1	0.2
iwc	0.1	0.2	0.2	0.3	38.4	0.1	2.6	2.0	27.6	6.7	22.9	1.1	63.1	25.9	3.5	20.0	11.1	106.1	7.7	6.9	1.9	3.8	1.8	2.1	1.8

4.1. Features of water consumption indicators

Table 3 presents data on direct water consumption and demonstrates that the amount of water directly consumed by the primary sector—the agriculture sector, including other food crops, non-food crops, and the rice sector—is much higher than that consumed by the processing sectors and service sectors. The agriculture sector's water consumption was above 4 billion m^3, and the rest of the sectors only consumed a small portion of this amount, about 456 million m^3. These results confirm the fact that agriculture is the main consumer of water resources in Bali, accounting for 89% of the total water consumption in the province. The top five dominant sectors in terms of direct water use in Bali province are food crops (53.3%), followed by non-food crops (17.8%), paddies (15.7%), hotels and restaurants (5.5%), and other grains (2.9%). The water consumption intensity of the agricultural sectors is significantly higher than that of the other sectors. Specifically, the water consumption per unit of output was highest for forestry and its products at 7,669 m^3 per million Indonesian rupiah (IDR). Interestingly, the overall agriculture sector consumed more than 89% of all water resources. However, except for forestry and its product sectors, paddy, maize, and other food crops sectors, and the non-food crops sector, the direct water consumption per unit produced was less than 800 m^3 per million rupiah. Thus, agriculture-related sectors have a pivotal impact on the use of water resources.

In the case of manufacturing and services sectors, the water consumption per unit of output is quite small. However, sectors like food, beverage, tobacco, coffee industries, paper industry, paper and cardboard goods, and hotels and restaurants exhibit a high level of direct water consumption and relatively high consumption per unit of output. Data from the padas stone and other minerals sector, the timber industry and wood products, the car body industry and transportation equipment, other processing industries, construction, the crafts and minerals industry, the other building materials (non-metal mineral goods) industry, and the paper industry, and paper and cardboard goods sector, demonstrate low direct water consumption per unit produced. Sometimes, these sectors are overlooked by water policymakers because of their low direct water consumption [61]. However, these sectors consume a great amount of water resources indirectly (see Table 4). Furthermore, the data can demonstrate the composition of their direct and indirect water consumption. The direct water consumption observed for the agriculture sectors are: rice (83%), maize (85%), other food crops (90%), plantation/non-food crops (67%), and livestock (76%). This indicates that the water used in their production processes is drawn from the available surface water (e.g., river and springs) and underground water resources. As stated above, the industrial and service sectors consume a large amount of water indirectly. In this view, the indirect water consumption appears to comprise a pivotal share of the water consumption in Bali province (Appendix Fig. 1).

If compared with the agriculture sector, the amount of water consumed by the manufacturing and service sectors is quite small. However, the indirect water consumption of the manufacturing and service sectors is significantly higher. Sectors such as padas stone and other minerals (8); textile, apparel, and leather goods industries (10); timber industry and wood products (11); paper industry, paper and cardboard goods (12); crafts and minerals industry (14); car body industry and transportation equipment (16); other processing industries (18); construction (20); transport and other transport services (23); communications, post, and Giro (24), among others, consume a small quantity of water directly, but their total consumption of water is somewhat high. Therefore, it can be presumed that these sectors consume a great amount of water indirectly, as shown in Table 4. This indicates that they only use a small amount of water directly in production but to produce the inputs made by the other sectors combined in their production processes, a high level of water consumption is required.

These sectors also have a large drag effect on the water consumption of the entire Bali economy. This can be observed by examining the water consumption multiplier (*wcm*) and the indicator of indirect consumption (see Table 4). If we only consider direct water consumption, sectors like livestock (5); food, beverage, tobacco, and coffee industries (9); timber industry and wood products (11); fuels and chemical industry, rubber, and plastics (13); crafts and minerals industry (14); car body industry and transportation equipment (16); and other processing industries (18) would be overlooked because their direct consumption is insignificant. However, the indirect consumption of these sectors is predominantly high, a point that can be ignored due to the high level of direct consumption of the other sectors. For each cubic meter (1 m^3) of water consumed directly in the livestock sector (5), an increase in production requires the consumption of an additional 38.35 m^3 of water by other production sectors. Likewise, in the food, beverage, tobacco, coffee industries (9), each 1 m^3 consumed directly requires the indirect consumption of an additional 27.58 m^3 of water by the other sectors. For the timber industry and wood products sector (11), for each 1 m^3 of water consumed directly, 22.90 m^3 is consumed indirectly. The level of indirect water consumption was also high for the fuels and chemical industry, rubber, plastics (13), the crafts and minerals industry (14), the car body industry and transportation equipment (16), other processing industries (18), and service sectors such as construction (20) and hotels and restaurants (22), which advances 3.77 m^3 for each 1 m^3 consumed directly. These results clearly indicate that the sectors with the highest indirect water consumption are those that are normally considered to be the driving forces behind Bali's economy due to the strong influence that demand for their respective products exerts on the production of the remaining sectors. In other words, an increase in production in these sectors requires additional inputs from the other sectors locally, provincially, and nationally.

4.2. Intersectoral water relationships

Table 5 exhibits the intersectoral water transaction coefficients. We first notice that the maximum water transaction coefficients are

Table 6
Matrix of intersectoral water relationships (W, in 10^4 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	Total
1	5,550	11	53	37	6,489	0	396	0	55,748	249	21	1	76	0	3	5	0	21	8	71	119	19,562	654	29	296	89,399
2	0	13,278	5	1	160	0	8	0	486	24	2	0	2	0	0	1	0	1	1	8	14	2,403	77	4	34	16,509
3	0	6	224,646	22	2,640	0	65	0	5,675	411	38	2	39	1	1	10	0	14	16	137	238	40,427	1,300	60	735	276,484
4	51	197	1,021	27,290	6,358	0	248	11	22,834	13,214	1,000	176	24,637	1	9	185	1	223	22	1,507	1,477	20,779	1,009	79	2,087	124,416
5	0	1	2	0	882	0	0	0	7	5	0	0	1	0	0	0	0	0	0	1	3	450	14	1	6	1,375
6	1	1	7	46	92	139	14	3	60	259	1,450	1	45	28	15	1	0	6	1	1,349	61	309	66	25	72	4,051
7	0	0	1	0	6	0	651	0	42	3	0	0	0	0	0	0	0	0	0	1	2	324	10	0	5	1,046
8	0	0	0	0	1	0	1	13	1	1	0	0	1	1	2	0	0	0	0	143	4	7	5	3	6	189
9	0	1	3	2	398	0	20	0	3,478	15	1	0	4	0	0	0	0	1	0	4	7	1,214	41	2	18	5,212
10	0	0	1	2	4	0	13	0	4	4,765	6	0	5	0	0	0	0	2	0	6	6	191	62	2	67	5,136
11	0	0	0	0	1	0	1	0	1	1	263	0	0	0	1	0	0	1	0	52	5	21	4	1	3	356
12	0	0	1	2	3	0	1	0	3	17	13	800	16	0	0	0	0	9	1	11	9	50	12	16	20	987
13	1	5	24	10	18	0	2	0	24	100	24	4	617	0	0	5	0	3	0	36	34	55	7	1	42	1,014
14	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	4	0	0	0	0	0	6
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	0	0	0	0	15	1	1	1	0	1	36
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	1	0	0	28
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1
18	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	8	0	1	1	1	0	0	0	13
19	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	14	0	0	7	1	1	1	30
20	0	0	2	2	9	0	9	2	6	9	4	0	4	0	1	0	0	0	1	1,131	31	55	39	20	44	1,368
21	0	3	36	7	254	0	26	0	79	157	49	2	42	0	2	6	1	4	1	194	1,667	651	41	5	41	3,268
22	0	2	61	12	66	0	16	0	48	276	25	1	22	0	1	7	0	8	10	90	157	27,887	891	41	394	30,016
23	0	2	23	4	150	0	15	0	45	143	31	1	24	0	1	6	1	5	5	123	28	400	4,701	22	64	5,795
24	0	0	0	0	3	0	1	0	1	18	4	0	2	0	0	0	0	0	0	5	14	22	7	224	11	313
25	0	2	12	7	51	0	63	0	27	106	33	5	31	0	1	4	0	5	6	109	170	278	112	10	2,839	3,874
Total	5,604	13,508	225,900	27,446	17,585	139	1,550	32	88,569	19,777	2,966	995	25,568	35	54	257	6	314	86	4,996	4,049	115,095	9,055	547	6,786	570,921

relatively low and that displays most water transactions among several sectors can be unseen because these transactions are limited to a few sectors in this developed new matrix. It is obvious that indirect water consumption is derived from non-food crops/plantation (4), as shown in Table 5. The matrix discloses that for each 1 m^3 of water consumed directly by the other processing industries (18), fuels & chemical industry, rubber, plastics (13), car body industry and transportation equipment (16), and livestock (5), sustaining this water demand requires an additional 75.9 m^3, 61.8 m^3, 15.1 m^3, and 14.2 m^3 of water, respectively, to be consumed by non-food crops/plantation. Similarly, for each 1 m^3 of water consumed directly by the other processing industries (18), Food, beverage, tobacco, coffee industries (9), and livestock (5), requires an additional 7.1, 18.0 and 14.5 m^3 of water, respectively, to be consumed by paddy (1).

On the other hand, it is shown that the sectors that stand out for their purchases are food, beverage, tobacco, and coffee industries (9), whose demand is fulfilled with products generated by rice (1), maize (2), other food crops (3), and plantation/non-food crops (4) with a high-water content. Other processing industries (18) are supplied mainly by plantation/non-food crops (4), rice (1), other food crops (3), and forestry products (6). Construction (20) is also supplied predominantly by plantation/non-food crops (4) and forestry products (6). The hotel and restaurants sector (22) are supplied with rice (1), maize (2), other food crops (3), and plantation/non-food crops (4). Apart from these four sectors, other significant sales are those made by the crafts and minerals industry (14) to Forestry and its products (6) and Trading (21). Lastly, we must observe that the highest ratio of sales in all sectors are transacted within the sectors that specify a high rate of self-consumption with concern to water. Table 6 presents the matrix of intersectoral water relationships; it can be read either by rows or by columns. The rows of the matrix can be interpreted as the sales of water that sector *i* makes to the rest of sector *j;* the column sums to the total amount of water sold by sector *i.* The columns of matrix *j* lists the purchases that sector *j* makes from the rest of the sectors *j*, so the row sums of this matrix provide us with an indication of the total water requirements of sector *j*.

4.3. Inter-industrial linkages

The inter-industrial linkages analysis can determine which key sectors have a greater impact on the entire water consumption process through both purchases and/or sales [16]. Table 7 classifies the key sectors with respect to the water consumption in the Bali province. Regarding the backward linkages index, the other food crops sector (3) shows the largest water backward linkages indices. Backward linkage represents that a unit increase in all sector's final demand will generate an above-average increase in water consumption of other food crops. Likewise, sectors like hotels & restaurants (22), food, beverage, tobacco, coffee industries (9), plantation/non-food crops (4), and fuels & chemical industry, rubber, plastics (13) have vital influence on total water consumption. Under the forward linkages indices, other food crops (3), plantation/non-food crops (4), rice crop (1), and hotels & restaurants (22) are the key water consumption-influencing sectors. This signifies that a unit change in their final demand will cause an above-average increase in water consumption in all sectors.

Remarkably, the hotels and restaurants sector (22) reveals that it has higher influence on water consumption both in its backward and forward linkages indices. Some sectors like livestock (5), forestry and its products (6), fishery (7), paper industry, paper and cardboard goods (12), transport and other transport services (23), and financial, public, community, cultural & entertainment and other services (25) and a few other sectors in manufacturing and service sectors have backward and forward linkage indices that are less than 1, which indicates less influence on water consumption.

Table 7
Linkage indices in terms of water consumption.

S. No.	Sector	Backward Linkage (BL)	Forward Linkage (FL)
1	Rice	0.2	3.9
2	Maize	0.6	0.7
3	Other food crops	9.9	12.1
4	Plantation or non-food crops	1.2	5.4
5	Livestock	0.8	0.1
6	Forestry products	0.0	0.2
7	Fishery	0.1	0.0
8	Padas stone and other minerals	0.0	0.0
9	Food, beverage, tobacco, and coffee industries	3.9	0.2
10	Textile, apparel, and leather goods industries	0.9	0.2
11	Timber industry and wood products	0.1	0.0
12	Paper industry and paper and cardboard goods	0.0	0.0
13	Fuel and chemical industry, rubber, and plastics	1.1	0.0
14	Crafts and minerals industry	0.0	0.0
15	Other building materials (e.g., non-metal mineral goods) industry	0.0	0.0
16	Car body industry and transportation equipment	0.0	0.0
17	Jewelry industry	0.0	0.0
18	Other processing industries	0.0	0.0
19	Electricity	0.0	0.0
20	Construction	0.2	0.1
21	Trading	0.2	0.1
22	Hotels and restaurants	5.0	1.3
23	Transport and other transport services	0.4	0.3
24	Communications, post, and Giro	0.0	0.0
25	Financial, public, community, cultural and entertainment, and other services	0.3	0.2

5. Limitations

The total number of sectors in this paper is 54 but there are no data for the mining and basic metal industry and other metal goods sectors. By excluding these two sectors, we aggregated 52 sectors into 25 sectors that were aggregated based on provincial industrial classifications [7]. This could create a bias because there is a larger number of different products included in one sectoral classification [39].

With the non-availability of direct water consumption data for some sectors—particularly, service sectors such as the financial, public, community, cultural and entertainment, and other services; communications, post, and Giro; and transport and other transport services—we have collected direct water coefficients based on the reports and documents provided by Udayana University, Indonesia, and the water statistics reports obtained from the Bali Statistical Bureau and Japan International Cooperation Agency (JICA).

The results are subject to considerable uncertainty and underlying variability. For instance, the Indonesia water-use data for 2005 and the economic IO table for 2007 are estimated. Moreover, the total Indonesian water use has considerable uncertainty because it is based on agency estimates. Various agencies, such as Badan Pusat Statistik Provinsi (BPS), FAO, United States Department of Agriculture, and United States Geological Survey, use different methods to estimate water use [80].

Finally, the regional IO table used in our analysis was for the year 2007 with the latest data available was created by the Bali Statistical Bureau. However, today's current economic structure is somewhat like 2007 because the tourism and agricultural sectors are still dominant sectors in this region. These limitations could be mitigated by a method that performs estimates for several years to show time-based developments.

Several studies feature the same limitation—unavailable water-use data for each sector. However, to overcome this constraint, Boudhar adopted a measure of sectoral water use that measures the volume of freshwater drawn from the water source by a given industry, including water use for industrial sectors in m^3, data which were taken from the FAO AQUASTAT [6,27,64]. The proportion of each sector's contribution can be derived from the vector of sectoral water use in monetary units for a selected country. The available data on the economic use of water are not structured according to the same group level. In this case, most studies have categorized a large number of disaggregated sectors into limited or aggregated sectors that can benefit from sourcing water consumption information from available data sources, which includes agricultural and related national and international organizations, meteorological departments, groundwater monitoring agencies, industrial reports, and private and government-owned industries [5, 79].

6. Policy implications

The production of key industrial sectors, such as rice, maize, other food crops, plantation, and livestock, not only increases water consumption in other sectors but also significantly increases water demand in crucial industrial sectors and the value added by other sectors. The Bali provincial government and the Indonesian government must focus on key industrial sectors when designing water-saving policies and enhancing water-use efficiency in lowland rice through water-saving technology (such as system of rice intensification cultivation and drip irrigation), water-saving varieties (such as the Ciherang variety), and timely repair irrigation channels to minimize water leakages. The other dominant service sector, tourism (hotels and restaurants), would increase the value added by the national economic system and have a higher impact on water consumption. If the water consumed by these sectors is restricted, it may affect economic growth. An increase in the value added of these key sectors will lead to an increase in water resources used in the whole economy. Moreover, when designing policies, the water policymakers should also consider indirect water use; the manufacturing (i.e., food, beverage, tobacco and coffee industry; timber industry and wood products, fuel and chemical industry; rubber, plastics, crafts and minerals industry; car body industry and transportation equipment; and other processing industries) and service sectors (construction) have a high level of indirect water use and less direct use. A unit change in the production of a sector with high indirect water use will unavoidably be redirected to the water use of the other sectors and may lead to destructive outcomes on the water resources in Bali province. Therefore, policymakers must consider both direct and indirect consumption when formulating policies.

The sustainable utilization of water resources is a challenging task in many countries. Particularly, rapid economic growth, urbanization, and increasing population create a high competition among key sectors in Bali. To maintain stability among key sectors, we came up with the following plans and actions that may help to tackle the challenges.

(1) With regard to agriculture water use, developing water-saving agriculture, controlling erosion and landslide management systems, preventing flood and reducing leakages in the drainage system, and adopting water-saving technologies, such as drip irrigation systems, in provinces with raw water.
(2) With regard to tourism (e.g., hotels and restaurants) and other manufacturing industries, quota water supply, paid water supply, and double charging can be implemented for industries that overuse groundwater sources. Drawing more groundwater affects the resource available to future generations; therefore, it is essential to consider allocating it over generations [81].
(3) In provinces where water resources are scarce, springs should be used as a source of irrigation water, cross-regional integrated water supply systems should be developed, low water consuming industries should be encouraged, and a water recycling system should be developed.
(4) The dominant key sectors—tourism, agriculture, and manufacturing industries—that follow sustainable water-use practices must be rewarded to serve as incentives, and there should be timely support from the government to water management organizations.

(5) The government or water management organizations must arrange yearly meetings to invite representatives from all the industrial sectors situated in the province or region to discuss the differences in the demand and supply of water in the province and share the innovative ideas of those who have already adopted water-use saving technologies for the benefit of others. Therefore, interest groups should be formed to impact the allocation process so that the end results best serve the interest of the society and environment. Likewise, reform efforts in water allocation, which result in a redistribution of economic benefits should be implemented [81].

7. Conclusions

In this paper, the proposed approach used specified water indicators and matrices to differentiate between direct and indirect water consumption. We also applied backward and forward linkage analysis to exhibit the key water-intensive sectors that influence the process of total water consumption. The results indicate that direct water consumption for agriculture sectors (i.e., rice (1), followed by maize (2), other food crops (3), plantation/non-food crops (4), and livestock (5)) was the highest. However, the manufacturing and service sectors consume a large amount of water indirectly. In this view, the amount of water consumed by the manufacturing and service sectors is quite small. Nevertheless, indirect water consumption appears to comprise a pivotal share of total water resources. For instance, sectors like livestock (5); food, beverage, tobacco, coffee industries (9); timber industry and wood products (11); fuels and chemical industry, rubber, and plastics (13); crafts and minerals industry (14); car body industry and transportation equipment (16); and other processing industries (18) have a high level of indirect water consumption.

According to the backward and forward linkages, other food crops (3); rice crop (1); hotels and restaurants (22); food, beverage, tobacco, and coffee industries (9); plantation/non-food crops (4); and fuels and chemical industry, rubber, and plastics (13) are the key influencing sectors on processing total water consumption. As expected, hotels and restaurants (22) are a high influencing sector both in backward and forward linkage analysis. We must admit the well-known fact that the greatest demand for water from the agricultural sectors, the hotels and restaurants and other sectors might specifically take place during the dry season, particularly from April to September. Moreover, this might sometimes cause problems in the production process due to a lack of the main inputs needed by the sector, which has consequences for the economy [61]. On this basis, total water consumption, that is, indirect consumption together with direct consumption, should be taken into proper consideration when planning the production economy of a province or country.

The Indonesia Climate Change Sectoral Roadmap synthesis report (2009) indicated that the Java-Bali region has already faced a deficit in its water balance and competition between economic sectors in using water resources is quite high [29]. In addition, distributing water resources between the various economic and non-economic users, such private household irrigation, farming communities, private commercial water companies, state-based water distribution, manufacturing industries, and tourism and other business activities can be a complicated and difficult task [55]. Therefore, our developed water matrices and indices will provide a useful tool for water and economic planning policymakers in devising sustainable water-saving solutions. The same methodology can account for not only productive factors but also for environmental variables. Moreover, this study will have significant practical implications for other regions that have similar situations of water resources or competition among industries.

Finally, we are aware that this paper is basically a partial primary approach to assessing the capacity of economic activities on Balinese water resources and that it could be more complete by also performing a comprehensive analysis of water consumption and economic variables such as value added and the employment generated by each sector. By doing so, we might obtain a comprehensible representation of the economic and environmental prominence of the water used by the different productive sectors. In addition, our work might also be improved by using a current IO table and observing variations in the variables, such as virtual water and interregional or interprovincial trade and other inclusions overtime. These are some of the potential future research areas of this study.

Credit author statement

Geetha Mohan: Conceptualization, Methodology, Data Interpretation, Reviewing, Writing-Original drat preparation. Saroj Kumar Chapagain: Methodology, Data Interpretation. Kensuke Fukushi: Supervision. Seksaan Papong: Methodology. I Made Sudarma: Data Preparation, Policy Implications. Andi Besse Rimba: Data Preparation, ArcGIS. Takahiro Osawa: Data Preparation.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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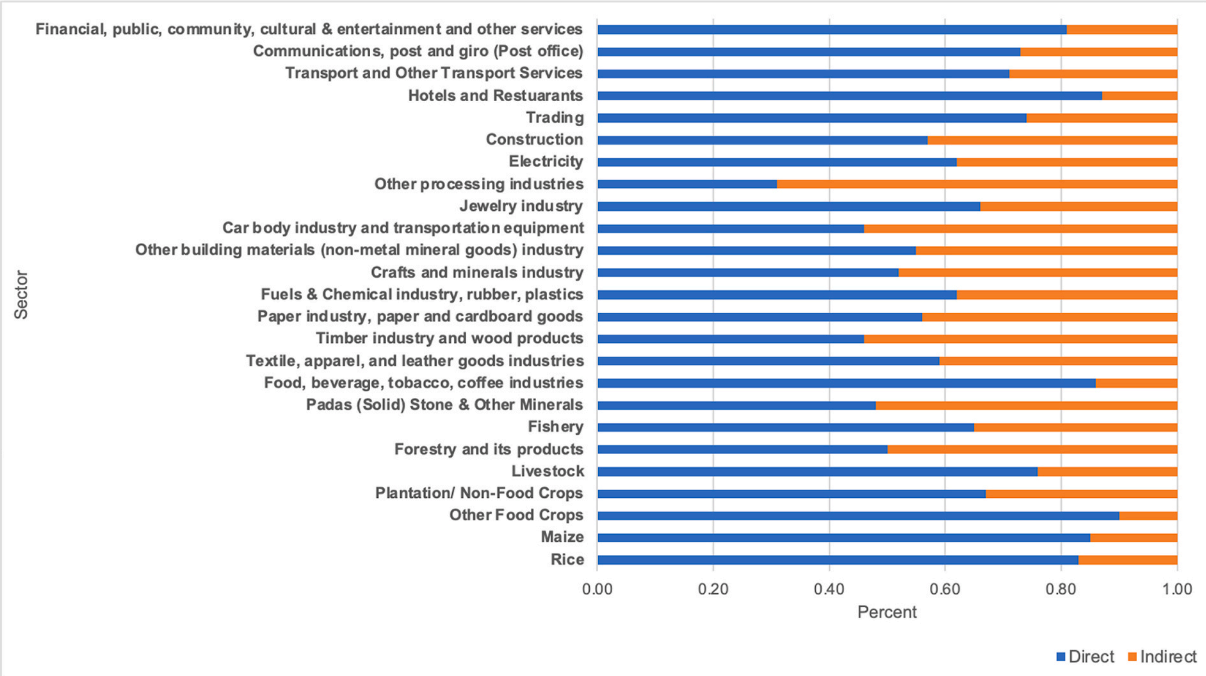
Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wri.2021.100141.

Appendix



Appendix Figure-1. Distribution of sector-wise direct and indirect water consumption in Bali province, Indonesia

Appendix 1. Water supply by Perusahaan Daerah Air Minum (PDAM) to different sectors

Sector	Categories of disaggregated sectors
Social/Public	Category of customers who deliver everyday services to the public interest and society in particular for low-income people, including public hydrants, public bathrooms, public toilets, water terminals, school social foundations public/private, orphanages, houses of worship, hospitals government, offices of mass organizations/political parties
Households	Category of household customers
Government Institution	Facilities of government agencies, institutions government, government-owned swimming pool
Trade Company	Street vendor stalls/stalls, shops/printing, private company offices, service bureaus, restaurants, inns/inns, private hospitals, non-broadcast radio government, private clinics, small workshops, small salons, barbershop hair, guesthouses, non-star hotels, notaries, lawyers, consultants, phone shop, catering, small clinic, pharmacy, drug store, business entity which is under the auspices of other small businesses as well importer company, exporter, realtor, commissioner, self-service, private hospitals type A, B and C, public swimming pools private sector, gas station, distributor, wholesaler, night club, café, discotheque, steam bath, star hotels, restaurants, department stores, supermarket, cinema, bank, badan usaha milik negara (Indonesian state owned enterprises), badan usaha milik daerah (Regionally-Owned Enterprises), perseroan terbatas (Limited Liability Company, commaditaire vennootschap (Limited partnership), karaoke place, large workshop, service station, showroom, high-rise building, condominiums and other large businesses
Industry	Covering the handicraft industry, household crafts, painting studios, small convection businesses, small farms and other small businesses/ industries also factories or the motorbike/car industry, chemical industry, mining, timber, shipbuilding, factories food/beverage, chemical/drug/cosmetic factory, textile factory, warehousing and factories or other large industries
Others	Seaports, rivers, airports, tankers and the like
Social/Public	Customers who deliver everyday services to the public interest and society in particular for low-income people, including public hydrants, public bathrooms, public toilets, water terminals, school social foundations public/private, orphanages, houses of worship, hospitals government, offices of mass organizations/political parties

Source: BPS, 2015 [9].

Appendix.2. Classification of Integrated sector for Bali Province

S. No.	Aggregated Sector	Sector
1	Rice	Rice
2	Maize	Maize
3	Other food crops	Cassava/Root crops, Vegetables and fruits, Peanuts, Soybeans, Other food crops
4	Plantation or non-food crops	Coconut, Tobacco, Coffee, Other Plantation Plants
5	Livestock	Big Livestock, Small Livestock, Livestock Slaughtering Services, Poultry and their products
6	Forestry products	Forestry and its products (all types of wood and commodities, firewood, tropical fruits, rattan, resin, roots, bamboo, honey, spices and other plants that grow in the forest). Forest activities includes logs (both derived from the cultivation of jungle and forests).
7	Fishery	Fishery (all fishing activities including catching, hatching and cultivating all types of fish and aquatic biota, both in fresh water, brackish water and sea). Commodities generated by fishing activities include all kinds of fish, crustaceans, molluscs, sea grass, and other aquatic organisms derived from the sea and open waters.
8	Padas stone and other minerals	Padas Stone (solid rock), Other minerals
9	Food, beverage, tobacco, and coffee industries	Rice milling, rice counseling, Copra industry, cooking oil, Food, beverage, tobacco, coffee industries
10	Textile, apparel, and leather goods industries	Textile, apparel, and leather goods industries
11	Timber industry and wood products	Timber industry and wood products
12	Paper industry and paper and cardboard goods	Paper industry, paper and cardboard goods
13	Fuel and chemical industry, rubber, and plastics	Fuels & Chemical industry, rubber, plastics
14	Crafts and minerals industry	Crafts and minerals industry
15	Other building materials (e.g., non-metal mineral goods) industry	Other building materials (non-metal mineral goods) industry
16	Car body industry and transportation equipment	Car body industry and transportation equipment
17	Jewelry industry	Jewelry industry
18	Other processing industries	Other processing industries
19	Electricity	Electricity
20	Construction	
21	Trading	
22	Hotels and restaurants	Restaurants, Star Hotel, Non-Star Hotel
23	Transport and other transport services	Land transportation, Sea transportation, Air Freight, Travel Bureau, Other Transportation Support Services
24	Communications, post, and Giro	Communications, post and Giro (post office and account)
25	Financial, public, community, cultural and entertainment, and other services	Banking, Money Changer, Rental of Buildings and Land, Other Financial Institutions, Company Services, Public Government Services, Community Social Services, Cultural Attractions, Entertainment Services, Personal and Others

Note: No (industries) data for sectors mining; and basic metal industry and other metal goods.

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