**ORIGINAL PAPER**

# An input–output approach to estimate the sectoral water footprint in Indonesia

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## Abstract

Examining a country's water footprint and underlying factors is essential to understand water resource problems and challenges. In Indonesia, along with the rapid economic development and population growth, the water crisis problem is suspected of gradually increasing. Limited information and statistics regarding water use result in minimal water monitoring in the country. It is also still unclear which sectors need to be prioritised and what efforts can be taken to anticipate a further water crisis. This study attempts to estimate in more detail the amount of water used during the production process in Indonesia. Using the concept of water intensity and water footprint and using information on economic structure for a decade, this study detects which sectors have the highest level of inefficiency in water use and then explores which aspects cause this high inefficiency. From 2005 to 2016, the estimated total water intensity value decreased, indicating an increase in water use efficiency. To see whether the increase in efficiency is followed by more efficient water use, sectoral water consumption is estimated using the water footprint approach. After estimating the water footprint, it is found that in some sectors, the increase in efficiency was followed by an increase in the amount of water used, better known as the Jevons paradox. The three sectors that experience the most serious Jevons Paradox are the plantation, horticulture, and livestock sectors, as these sectors have a high level of gross water and virtual water footprint. It is anticipated that if no action is taken to increase efficiency, it will result in a waste of resources and a drain on the national budget, as the government may need to spend additional funds for the 'water budget' when producing commodities.

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**Graphical abstract**
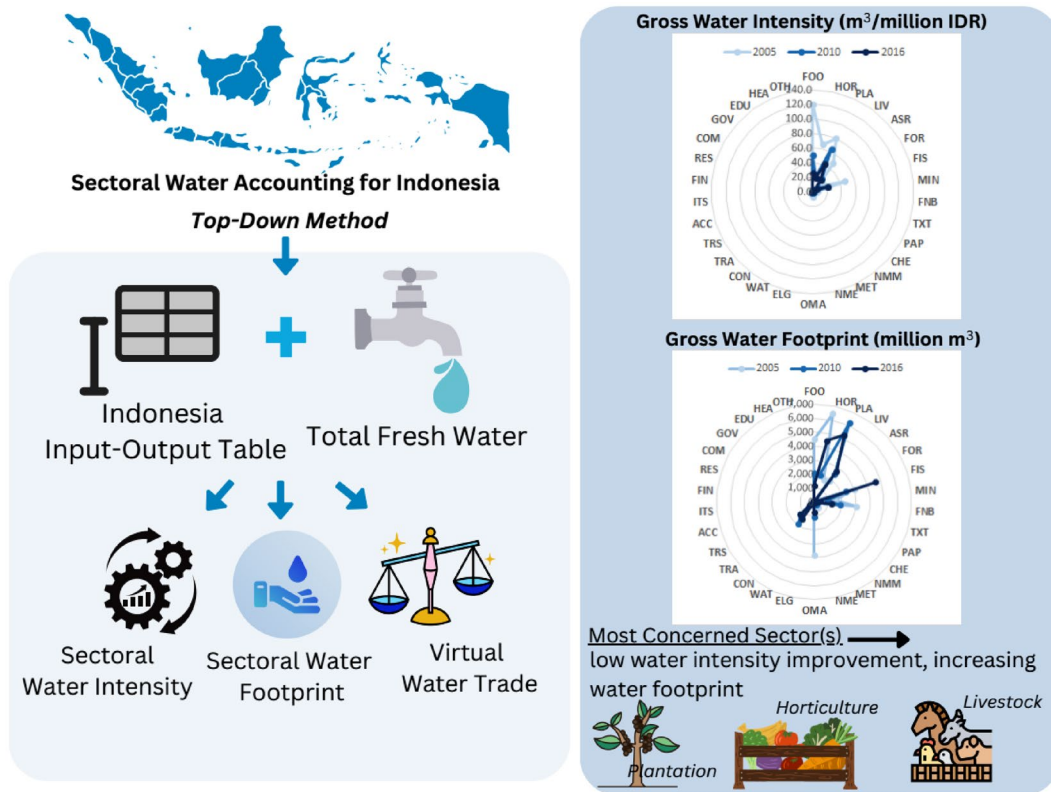
## Introduction

Water is a basic good and a human right. It is an essential input for the economy to function. Despite its characteristics as a renewable resource, this resource is site specific, easily polluted and sensitive to temperature changes. This has resulted in many areas experiencing water scarcity suitable for consumption, and water sustainability is becoming a global concern (Grego and Antonelli 2015).

As a tropical archipelagic country, Indonesia is blessed with abundant water resources. However, as with most developing countries, Indonesia lacks water monitoring systems, causing a water supply and demand data shortage, leading to a lack of integrated water management (UN-Water 2021). Based on the hydrological cycle, sectoral water consumption details are critical because the amount of water available will always be constant. However, sectoral competition to obtain this resource will continue to grow along with increasing economic activity and Indonesia's population (Chairunnisa et al. 2021). At the same time, Indonesia faces water stress threats throughout the country. The World Bank (2021) reported that by 2021,

half of the country's gross domestic product (GDP) was produced in river basins that suffered high or severe water stress in the dry season. As more than half of Indonesia's rivers are also heavily polluted, it is predicted that without significant changes made by 2045, two-thirds (around 67%) of Indonesia's GDP will be generated in highly or severely stressed basins, indicating that water resources that can be used for economic activity will be significantly lesser than their potential. Thus, Indonesia must pay attention to its water conditions and overcome its water crisis.

Due to the unavailability of specific data, there is no information on sectors that are the most water-intensive and efficient in consuming water. The statistical data provided by Indonesia regarding water resources are still limited. The information on water supply is limited to the recorded amount of supplied water provided by state-owned water companies. There is also minimal data on total water withdrawn and no detailed information on the water demand. This is mainly because many activities (especially for industry and agriculture) are not metered and are often accessed for free (Olmstead 2010). As water is a part of the production process, the data regarding

goods production can be utilised to measure the sectoral water demand in a country.

Considering the importance of information about water consumption and the complexity of gathering data directly from the field, methods to estimate water consumption trends are very beneficial. Calculating the virtual water footprint (VWF) is an alternative way to measure sectoral water demand in a country based on socioeconomic data. Many researchers have widely applied this methodology, and several governments have adopted it to evaluate their countries' water consumption related to socioeconomic activities. Governments in developing countries with limited national budgets can then frame appropriate policies and determine sectors that must be prioritised (Weinzettel et al. 2014).

There are two common methods to assess water footprints. The *bottom-up method* multiplies the sum of goods and services by the virtual water content, and the *top-down method* assesses the production process and calculates the total use of domestic water resources plus the imported virtual water flow minus the exported water flow (Wang et al. 2013). Most national-level top-down water accounting methods utilise the input–output (IO) table to calculate the sectoral water footprint at each supply chain stage. This study uses the top-down method, considering the close relationship between production activity and water. It aims to estimate sectoral water use in Indonesia by utilising a top-down water accounting method and evaluating the water consumption pattern and trend so it can be a scientific input for the policy maker in organising an efficient policy package regarding water resources. As this method also utilises existing national databases, this study also tries to offer an alternative way to assess water use in the economy and close the literature gap on this issue.

Compared with existing research, there are some novelty points in this study, namely:

1. The latest Indonesia IO table (2016) is used in this study and compared with the previous IO table (2005 and 2010) to understand Indonesia's water footprint trend.
2. This study provides a method to estimate sectoral water use in Indonesia that is not yet available in any Indonesian database. By using this method, the exhaustive data collection and processing for water resources can be minimised, as estimation is conducted using the available database. This contribution is valuable, considering that water footprint accounting in Indonesia is mainly challenged by its geographical conditions.
3. This paper considers three factors in determining the most concerning sector regarding water consumption: water intensity (representing efficiency improvement), water footprint (representing water consumption) and virtual water trade.

As one of Indonesia's initial top-down water footprint accounting, it is hoped that the study can also initiate more research and discussion on water resource sustainability in the country. At the end of this study, there are also some policy recommendations policymakers can consider to manage water resources.

Several components will be estimated in this study: (1) water intensity, to see how efficient a sector is in using water during the production process; (2) water footprint, to estimate the gross quantity of sectoral water consumption; and (3) VWF/virtual water trade, to see the virtual water flow through international trade and to view Indonesia's reliance on importing water-intensive goods from other countries. The basic information on Indonesia's supply–demand structure was acquired from its IO tables for one decade.

## Literature studies on water footprint accounting

Water accounting was mainly done using bottom-up approaches, such as crop modelling or 'rule of the thumb' calculation, which estimates the amount of water required to produce a product unit. This bottom-up method is beneficial for measuring water use in a period for a specific area, sector, or crop. However, this method is impractical for estimating water use at a larger scope area such as the national, regional or even global level. Calculations using the bottom-up method also often fail to consider water content at each stage of the product supply chain (Yang et al. 2013). Overcoming embedded water at each production stage is essential, especially for the industrial sector, because this sector processes a lot of raw and semi-finished materials, where this sector may consume much water indirectly rather than directly, as happened in the agricultural industry. Considering some limitations of the bottom-up approach, the water footprint estimation method continues to be developed, resulting in the emergence of a top-down approach to water accounting.

IO and multi-regional IO (MRIO) tables are the two most widely used tools for estimating water use with a top-down approach. IO and MRIO tables provide detailed information regarding sectoral supply and demand in a country or region, including intermediate demand and international trade. This information provides a more detailed estimation of the water needed by each sector, including direct and indirect water consumption. In addition, because IO and MRIO tables are prepared using monetary units, the efficiency value of water use for each monetary unit can be measured in addition to the total quantity of water use. In other words, this top-down method makes it possible to calculate efficiency and the total amount of water used simultaneously (Duarte and Yang 2011). It

is important because an increase in efficiency does not always mean a decrease in demand. In many cases, efficiency improvement has a rebound effect, especially concerning natural resources like water (Dumont et al. 2013).

By tracking the previous literature, the IO table for water accounting estimation has been widely used since the 2000s as the extension of the development of the green IO table. Using the MRIO-2014 data from the Global Trade Analysis Project database, Zhan-Ming and Chen (2013) assessed the global water footprint with a top-down approach. Their analysis found that India, China and the USA are the world's largest virtual water consumers.

As one of the largest global water consumers at the Asian level, China has become the country most active in conducting studies on water footprint at the national and city levels. Unlike global and regional studies, China mainly utilises national or sub-national IO tables, making the assessment more accurate in describing the country's specific conditions. One of the earliest studies on the water footprint study for China that can be traced was the study of Zhao et al. (2009). This study estimated China's direct and indirect water footprint. They found that compared to bottom-up and global calculations (Hoekstra 2003), China is a net global water exporter rather than a water importer. This study also shows the importance of using a national database and top-down accounting to describe the national situation better.

With more data and information over a longer period, further insight into improving water use efficiency can also be estimated. Zhao et al. (2010) used the provincial-level IO table and took into account water intensity. Their study found that in the period 1997 to 2002, in the provinces around the Haihe River basin, the agriculture and food processing sectors were two sectors that were less efficient in water use. Therefore, it was recommended to boost the technology adoption for these sectors to increase efficiency and offset production activities in this sector which are very high.

Wang et al. (2013) conducted a more comprehensive study. Their study specifically estimated Beijing's water footprint. Using the IO table for 2002 and 2007, their study found that along with the rapid technological development in Beijing, the efficiency of water use in this city is higher than in most cities in China. However, they also found that during the estimated period, there were indications that the quantity of water used, especially for food and tobacco processing, was increasing rapidly. Fan et al. (2019) also conducted extensive studies of this matter using a more updated IO table (China National IO table for 2002, 2007 and 2012), distinguishing rural and urban households and confirming that the country's water footprint mostly comes from the agriculture sector—it is still struggling with water efficiency improvement due to infrastructure issues, especially in rural areas. At the same time, the consumption of

agricultural products is increasing significantly domestically and internationally.

To the author's knowledge, until this paper was written, there were relatively few studies on estimates related to detailed water use or water footprint in the Southeast Asian region, including Indonesia. This is most likely because water resources in this area are abundant and easily accessible, so literacy related to the urgency of water resource accounting and assessment is still low (Maniam et al. 2021). Especially for archipelagic countries, a geographical challenge also makes water resources accounting harder to maintain, track and address (Trias 2021).

## Method

The top-down method of water footprint estimation generally estimates sectoral water demand based on a country's supply and demand structure. Information on Indonesia's economic structure was obtained from the Indonesia IO table. This IO table must be analysed before it can be modified to estimate sectoral water demand.

First, the IO analysis is conducted until the Leontief Inverse Matrix is obtained. Following this, the total freshwater use is divided into sectors using the proportion obtained from this matrix. Thus, water intensity is obtained. The unit of this water intensity is the volume of water per monetary unit. The total quantity of sectoral water use can be estimated by calculating the water footprint. This total water footprint can be calculated by multiplying this water intensity by the sectoral final demand. The virtual water trade can also be estimated by making separate calculations by multiplying the water intensity with the sectoral export and import. Figure 1 describes the general process of this water footprint calculation.

Each step has some mathematical equation. The detail of the estimation steps for this study is described as follows.

### Traditional input–output (IO) table analysis

The Indonesia IO Table is constructed to give an overview of the interrelationships between sectors in the economy as a whole. The relationships between sectors are presented in a matrix form consisting of several rows and columns. The rows depict how the output of a sector is allocated to meet its intermediate and final demand. The columns represent the inputs needed to produce a good, including the primary and intermediate inputs (production factors). The total input and output in an IO table need to be balanced, meaning that each produced good is assumed to be consumed—either by intermediate input, consumption or international trading. Table 1 describes the formation of the Indonesia IO Table. In this table, the flow of goods and services is measured in
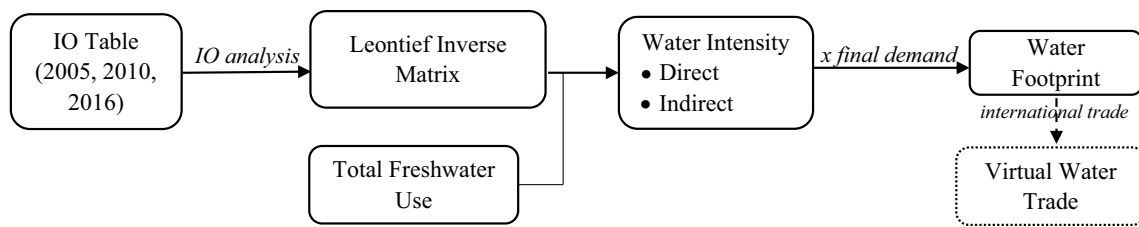
**Fig. 1** Overview of top-down estimation process of water intensity and water footprint by utilising the IO table

**Table 1** General depiction of the structure of the Indonesia Input–Output (IO) table

| Output allocation | | | | | | | |
|---|---|---|---|---|---|---|---|
| Input structure | | | Intermediate demand | | | Final demand | Total output |
| | | | Production sector | | | | |
| | | | 1 | 2 | $n$ | | |
| Intermediate input | Production sector | 1 | $x_{11}$ | $x_{12}$ | $x_{1n}$ | $F_1$ | $X_1$ |
| | | 2 | $x_{21}$ | $x_{22}$ | $x_{2n}$ | $F_2$ | $X_2$ |
| | | $n$ | $x_{n1}$ | $X_{n2}$ | $x_{nn}$ | $F_n$ | $X_n$ |
| Primary inputs | | | $V_1$ | $V_2$ | $V_n$ | | |
| total input | | | $X_1$ | $X_2$ | $X_n$ | | |

monetary value, as they are calculated based on the economic transactions in the country. The final demand in the Indonesia IO Table consists of household and government consumption, fixed capital formation (investment), export and import.

In the classic IO table, the total output can be written as:

$$X_i = \sum_{j=1}^{n} x_{ij} + Y_i \tag{1}$$

where $X_i$ is the gross output of sector $i$, $Y_i$ is the total final demand of sector $i$ and $x_{ij}$ is the intermediate inputs from sector $i$ to sector $j$. This IO table can be assessed further with some matrix treatment. The first step is to calculate the *technical coefficient matrix*. This technical matrix shows the direct productive interdependence of all sectors of the economy. It represents the production structure of the economy at a given time and is defined as a ratio of a product from sector j to produce one unit of its product (Raa 2006). It can be mathematically written as:

$$A = [a_{ij}], a_{ij} = x_{ij}/X_j \tag{2}$$

where A is the technical coefficient matrix, $a_{ij}$ is the direct input from sector $i$ that is needed to increase the output in sector $j$ by one monetary unit.

After gaining the technical coefficient, the *economic multipliers* (how much the intermediate input may change by the final demand change) can be seen by calculating the *Leontief*

*Inverse Matrix*. This inverse matrix also describes the spillover effect that arises between various economic activities, directly and indirectly. The Leontief Inverse Matrix can be calculated as follows:

$$B = [I - A]^{-1} = [b_{ij}] \tag{3}$$

Here, $B$ is the Leontief inverse matrix, $I$ is the identity matrix and $b_{ij}$ is the input from sector $i$ that is necessary to fulfil one monetary unit of final demand in sector $j$.

## Calculating the water intensity and water footprint

A further modification can be done after the Leontief Inverse Matrix is gained. This study attempts to estimate how much water each sector consumes in production as well as the final demand. Two types of water calculation are used in this study—water intensity and water footprint.

Water intensity represents how much water is needed to produce one monetary unit of goods. It also represents the efficiency of water consumption in producing a good/service. The unit for water intensity here is m3/million Indonesian Rupiah (IDR). A decrease in water intensity indicates that less water is needed to produce one monetary output unit. The gross water intensity (GWI) consists of direct water intensity (DWI) and indirect water intensity (IWI).

By following the water intensity calculations proposed in the studies of Wang et al. (2013) and also further adopted by Fan et al. (2019), the DWI is calculated as follows:

$$DWI = [w_j], w_j = W_j/X_j \qquad (4)$$

where $W_j$ represents the water withdrawal in sector $j$, and $w_j$ represents the direct water withdrawal coefficient in sector $j$.

The GWI is calculated by multiplying the DWI by the Leontief inverse matrix (see Eq. 3), or it can be written as:

$$GWI = DWI \times B \qquad (5)$$

As the GWI consists of DWI and IWI, the IWI can be calculated by subtracting gross water from the DWI:

$$IWI = GWI - DWI \qquad (6)$$

The water intensity only describes the efficiency in water consumption and not the quantity of the consumed water. The quantity of water consumed by each sector is estimated by calculating the water footprint. This estimation is important because the efficiency improvement does not necessarily indicate a reduction in water consumption.

The estimation of gross water footprint (GWF) is gained by following this equation:

$$GWF_i = GWI_i \times F_i \qquad (7)$$

where $GWF_i$ is the GWF in sector i, and $F_i$ is the total final demand in sector i.

From this modified IO table, the virtual water flow can also be calculated. This virtual water flow describes the tendency of a country to export or import water-intensive products. It is called virtual water because it describes the water content of the traded goods/services and not the direct import/export of water.

The estimation is calculated as follows:

$$IVW_i = GWI_i \times IMP_i \qquad (8)$$

$$EVW_i = GWI_i \times EXP_i \qquad (9)$$

$IVW_i$ and $EVW_i$ mean the imported virtual water and exported virtual water in sector $i$, respectively. The $IMP_i$ is the total imported good in sector $i$, and $EXP_i$ is the total exported good in sector $i$. After gaining the $IVW_i$ and the $EVW_i$, the virtual water flow ($VWF_i$) can be calculated by subtracting $IVW_i$ with $EVW_i$.

$$VWF_i = IVW_i - EVW_i \qquad (10)$$

A positive value in $VWF_i$ indicates more water inflow, meaning that the country imports water-intensive products to fulfil domestic demand.

## Data

The main information on the initial economic structure, including the allocation of the inputs and outputs in the economy, is gained from the Indonesia IO Table. The IO tables over a period of one decade are used for this study to obtain a more comprehensive estimation and to capture the water use trends; these include the Indonesia IO Table 2005 (BPS 2008), the IO Table 2010 (Badan Pusat Statistik 2015) and the IO Table 2016 (BPS 2021). In Indonesia, the IO table is updated every five years because it is assumed that the economic structure will not change significantly every year. The process of updating, processing, and balancing is also very time-consuming and costly. Thus, the five-year gap is considered the most preferred time range for updating the IO table. Due to delays in preparing the Indonesian Supply and Use Table, the 2015 IO table information shifted to the 2016 IO table.

There are 175 sectors in the original IO table for 2005 and 185 sectors in the original IO tables for 2010 and 2016. For conciseness, those sectors are aggregated into 30 sectors. To ease the analysis, these 30 sectors are also grouped into several commodity groups, such as agriculture, mines and industries, and utilities and municipalities (including service sectors). Table 2 describes the IO Table aggregation and sector grouping for this study.

As there are no documents and official statistics on the gross water consumption in Indonesia, this study uses information on gross water withdrawal for agriculture, industry, and municipalities from the AQUASTAT of the FAO. To check the consistency of the AQUASTAT data, those data are then compared to the strategic plan documents of the Directorate General of Water Resources of the Indonesia Ministry of Public Works and Public Housing for the periods 2015 to 2019 (Kementerian 2015) and 2020 to 2024 (Kementerian 2020). The available gross water withdrawals

**Table 2** Grouping and the sector classification in this study

| Commodity groups | Sectors in IO Table 30 sectors |
| --- | --- |
| Agriculture | (1) Food crops, (2) horticulture, (3) plantation (seasonal and annual), (4) livestock, (5) agricultural services, (6) forestry, (7) fisheries |
| Mines and industries | (8) Mining, (9) food and beverages, (10) textile, (11) paper and wood, (13) chemical, (14) Non-metal minerals, (15) metal-based, (16) non-metal based, (17) other manufactures |
| Utilities and municipalities (including services) | (18.) Provision of electricity and gas, (19) water and waste management, 20.) construction, (21) trade, (22) transport, (23) accommodation services, (24) information and technologies (IT), (25) financial services, (26) real estate, (27) company services, (28) public governance, (29) educational services, social and health services, (30) other services |

in those documents are limited to only gross water values in 2012 and 2016. After comparing the data obtained from AQUASTAT and information from the government's documents, no significant discrepancy is found between the two sources, so the data from AQUASTAT is used with the consideration that this database provides complete time series information.

## Study limitations

The method is only for estimating and seeing the trend of sectoral water use in Indonesia. As the primary data used in this study are economic databases (in this case, IO tables), the estimation is limited to how much water is used to support human socioeconomic activities. There are also many types of water, such as green water (rainwater), blue water (surface and groundwater) and grey water (water to dilute pollution). For this study, it is assumed that the water estimated is blue water. Thus, the estimation does not include the green and grey water in this instance.

## Results

### Water intensity

Water intensity describes how much water is used to produce one monetary unit of production. In this study, the monetary unit is one million IDR, following the monetary unit of the Indonesia IO table. A reduction in water intensity describes efficiency improvements in economic terms, meaning that the sector requires less water to produce more output. In order to obtain a more comprehensive picture of water use efficiency in Indonesia, the total and sectoral water intensity are estimated.
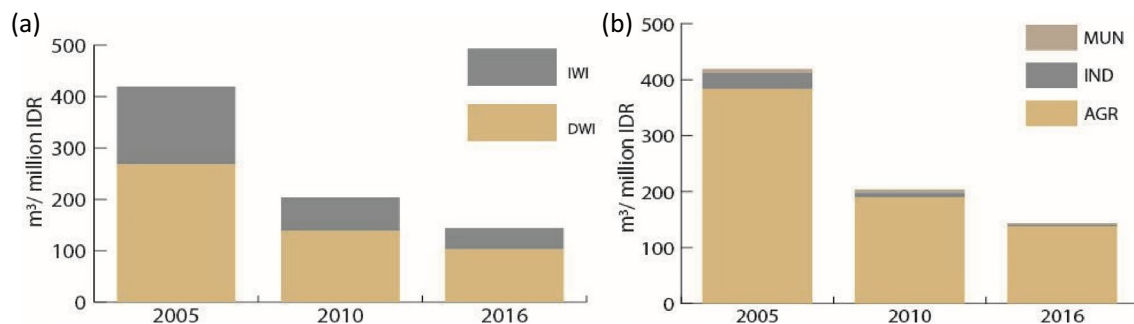
### Total water intensity

There are two types of water intensities: direct water intensity (DWI) and indirect water intensity (IWI). The DWI describes the amount of water input directly used to generate one monetary unit of final demand, and the IWI describes the water input that is indirectly used because it is attached to the intermediate inputs/intermediate demand. Both of these water intensities are considered and estimated in this paper.

Based on the calculation results in this study, there has been a decrease in water intensity in the production process in Indonesia over a period of one decade, which indicates that there has been an efficiency improvement in the overall use of water in the process of producing goods and services in Indonesia. As seen in Fig. 1a, in 2005, it was estimated that around 420 $m^3$ of water was needed to produce one million IDR of products. This value increasingly declined by more than half to 203 $m^3$/million IDR in 2010 and 143 $m^3$/million IDR in 2016 (Fig. 2a). The biggest proportion of this water intensity comes from the DWI, which is an average of 68% of the total water intensity.

Within the commodity group, it is obvious that the water intensity is significantly higher in the agricultural group than it is in the other groups (Fig. 2b). Around 94% of freshwater is estimated to be used by this group. It is undoubtedly driven by higher water use in this group, as water is also a direct input in cultivation activities.

In this study, the agricultural group consisted of several sectors, including food crops (FOO), horticulture (HOR), seasonal and annual plantation (PLA), livestock (LIV), agricultural services (ASR), forestry (FOR) and fisheries (FIS). Water intensity experienced a downward trend over one decade in the agricultural sector. As depicted in Fig. 3a, it was estimated that at least 383.50 $m^3$ of water was needed to produce one million IDR of goods



Notes:
*Water legend: DWI: direct water intensity; IWI: indirect water intensity*
*Sector legend: AGR: agriculture; IND: Mines and industries; MUN: Utilities and municipalities*

**Fig. 2** The Composition of Estimated Total Water Intensity 2005–2016, **a** Total water intensity by intensity type; **b** Total water intensity by sector. Notes: Water legend: DWI: direct water intensity; IWI: indirect water intensity. Sector legend: AGR: agriculture; IND: Mines and industries; MUN: Utilities and municipalities
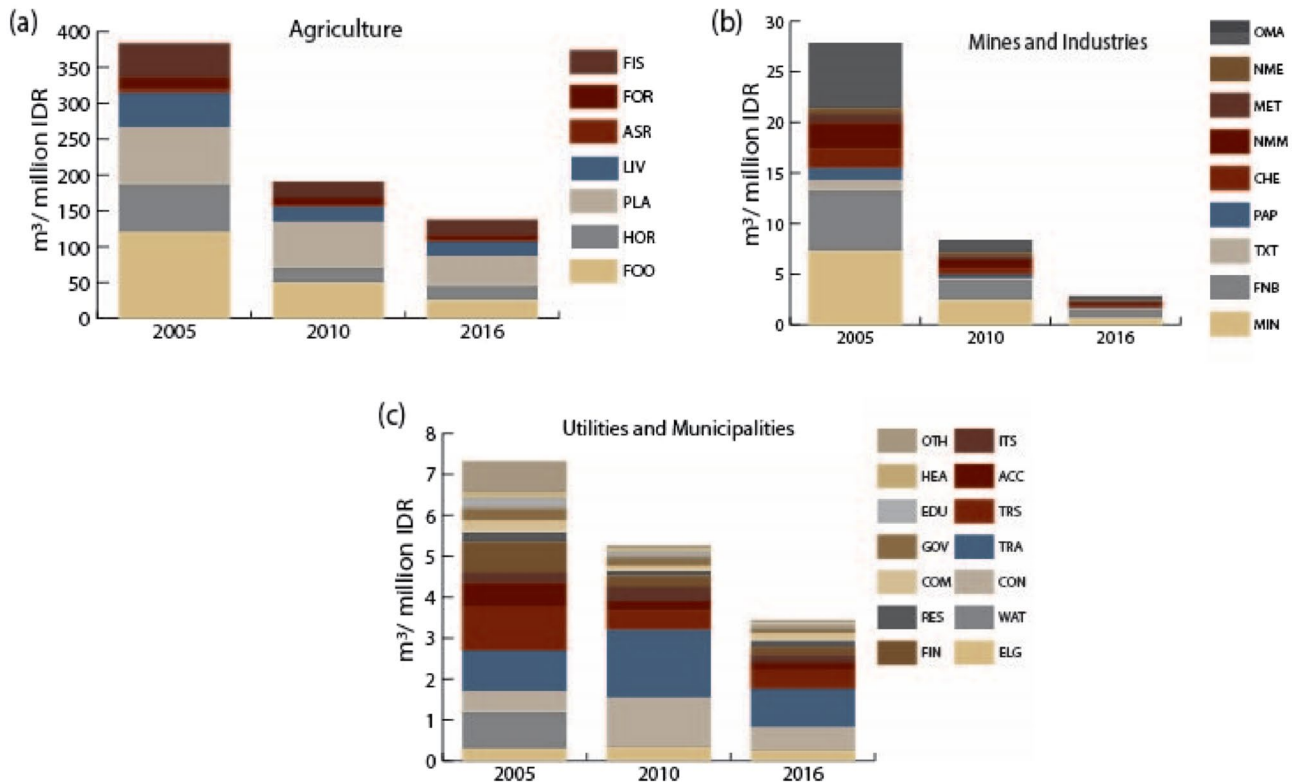
Fig. 3 The Composition of Estimated Total Water Intensity in each group, 2005–2010. Notes: Agriculture: FOO: food crops; HOR: horticulture; PLA: plantation; LIV: livestock; ASR: agricultural services; FOR: forestry; FIS: fisheries. Mines and Industries: MIN: mining and excavation activities; FNB: food and beverages industries; TXT: textiles industries; PAP: paper and wood industries; CHE: chemical industries; NMM: non-metal minerals processing industries; MET: metal-based industries; NME: non-metal industries; OMA: other manufacturers. Utilities and Municipalities: ELG: provision of electricity and gas; WAT: water and waste management; CON: construction; TRA: trade; TRS: transportation; ACC: accommodation services; ITS: information technologies (IT) services; FIN: finance services; RES: real estate; COM: company services (consultation); GOV: public governance; EDU: education services; HEA: health services; OTH: other services

in Indonesia in 2015. Along with increased efficiency and agricultural technology in the country, this intensity value decreased to only about 190.21 m³/million IDR in 2010 and 137.49 m³/million IDR in 2016. In most cases, FOO consumes more water than other sectors in the agriculture group. This is especially true in Indonesia, where rice is the main staple food in the country, and paddy rice is normally cultivated in constantly flooded rice fields. The estimation in this study shows a slightly different trend in water intensity in Indonesia. The total water intensity of FOO was indeed the highest in 2005, with around 120.35 m³/million IDR of output. However, the intensity halved to only 49.84 m3/million IDR in 2010 and 25.29 m³/million IDR in 2016. The result follows the success of Indonesia's application of the System of Rice Intensification technology (Budianto et al. 2020) and its use of rice varieties that are more water-efficient and with lower emissions, such as the *Inpari* rice varieties that were introduced (Wihardjaka and Sarwoto 2015). Interestingly, compared with other sectors in this agriculture group, Indonesia's highest water

intensity since 2010 came from the PLA sector. Despite the decrease in total water intensity from 2005 to 2016, the declining rate is less significant than that which occurred in the FOO and other sectors. The level of water intensity from the PLA sector was the highest compared to the other subsectors since 2010, with an estimated water intensity of 64.40 m³/million IDR in 2010 and 42.22 m³/million IDR in 2016. This result indicates that the efficiency improvement in the PLA sector cannot keep up with the high and rapid increase in production. With the higher production target and low-efficiency improvement, more inputs (including water, fertiliser and pesticides) are required. This makes it relatively expensive to produce input in the PLA sector, as it demands more water input to produce a unit of output compared with the other agricultural sectors.

Other sectors that show high water intensity besides FOO and PLA are the HOR and LIV sectors. On average, around 35.23 m³ of water is needed to produce the one million IDR of HOR products; for LIV, the water intensity is around 29.59 m³/million IDR.

Although not as big as the agriculture group, the water consumption from the mines and industries is also expected to be high. The estimation of total water intensity for this group can be seen in Fig. 3b. For the mines as one of the world's biggest mineral producers, particularly in coal, Indonesia's mining sector is estimated to consume large amounts of water. Fortunately, it is also becoming more efficient. This is indicated by the total water intensity value of only 0.63 m³/million IDR in 2016, a significant decrease compared to the water intensity in 2005, which was estimated at 7.29 m³/million IDR and 2.42 m³/million IDR in 2010. Based on the estimation results in 2005, 2010 and 2016 for the industrial sector, 20.57 m³/million IDR, 5.93 m³/million IDR and 2.24 m³/million IDR, respectively, come from the food and beverage (FNB) industries, which has the biggest scale in the country.

As a country with a rapid growth of population, it is also very important to see the dynamic in the water intensity in utilities and municipalities, as can be seen in Fig. 3c. The water intensity in the utilities and municipalities sectors is low compared to the other commodity groups, such as agriculture and industry, and it is interesting to understand the water intensity pattern in their subsectors, as the efficiency improvements in these groups are relatively lower. For example, in the utility sector, which consists of electricity and gas, there is no visible trend of declining water intensity from 2005 to 2016. It ranges from 0.25 to 0.33 m³/million IDR. In the municipalities group, the sectors with the highest water intensity are the trade (TRA), construction (CON) and transportation (TRS) sectors. The TRA sector's water intensity fluctuated from only 0.99 m³/million IDR of total water intensity in 2005 to 1.66 m³/million IDR in 2010, then slightly decreased to 0.94 m³/million IDR in 2016. There is no apparent decreasing trend in water intensity in the CON sector compared with 2005. Total water intensity in 2005 was 0.51 m³/million IDR, and then it increased to 1.20 m³/million IDR in 2010. In 2016, the water intensity had decreased to 0.56 m³/million IDR. Although lower than in 2010, it was still higher than in 2005, so there are still inefficiencies in water use in this subsector.

Another sector that has high water intensity in the municipalities group is the TRS sector. Along with the continued development of technology in the TRS subsector, there has also been an increase in efficiency resulting in a decrease in the estimated water intensity since 2005; it reached 1.09 m³/million IDR in 2005 and moved to 0.46 m³/million IDR in 2010. Interestingly, instead of decreasing, it is estimated that the water intensity in 2016 slightly increased to 0.47 m³/million IDR (Fig. 3c).

The dynamic of water intensity in each sector is influenced by the dynamics of DWI and IWI in each sector. In the agricultural sector group, for example, DWI dominates, but in other sector groups, IWI dominates. Thus, it is also important to look at DWI and IWI for each group.

### Direct water intensity

The DWI here refers to how much water is directly needed or used to produce a one million IDR of output. In this study, the DWI is compared by sector, and because some sectors dominate water use, it is divided into several groups to facilitate assessment: (1) agriculture, (2) mining and industries and (3) utilities and municipalities (Fig. 4).

**Agriculture** Water use in the agricultural group is higher than in the other sectors, as water and land are essential production factors. The direct use of water in agriculture mostly comes from watering activities during cultivation. As seen in Fig. 4a, the DWI in 2010 was nearly half of the DWI in 2005, while the reduction was only around 25% from 2010 to 2016. This is in line with the increase in agricultural technology, which accelerated rapidly in the 2005–2010 period. During that period, the Indonesian government was intensively carrying out agricultural intensification, including investing in agricultural technologies (Suhendrata 2008). In 2005, the government also began planning agricultural revitalisation, so in 2006, Law No. 16/2006 was issued concerning the Agricultural, Livestock and Forestry Extension System, followed by the Ministry of Agriculture Regulation No. 273/2007 regarding the mechanism of agricultural extension, which highlighted the importance of counselling for farmers (Vintarno et al. 2019). With this counselling, farmers also receive training regarding the proper, effective and efficient allocation and management mechanism of agricultural inputs. This then creates a rapid increase in efficiency in the agricultural sector in Indonesia, including in the use of water resources. After 2010, there were still efficiency improvements but not as significant and rapid as during 2005–2010.

**Mining and industries** The direct water use in mining and industry is not high, as these sectors mostly consume water 'indirectly' as a result of the use of intermediate inputs from various sectors. Direct water uses in the mining sector, especially mineral mining, mostly occur during mineral extraction, including during the chemical and physical separation of the minerals. The water in mining is also often used for washing equipment and cooling systems when needed (Prosser et al. 2011).

While it is very common that the direct use of water in the industrial sector is less than 10% of the total use of freshwater, the efficiency in the industrial sector also increases rapidly and significantly because this sector is the fastest in adopting various innovations and more advanced technologies (Blackhurst et al. 2010). The DWI for this sector
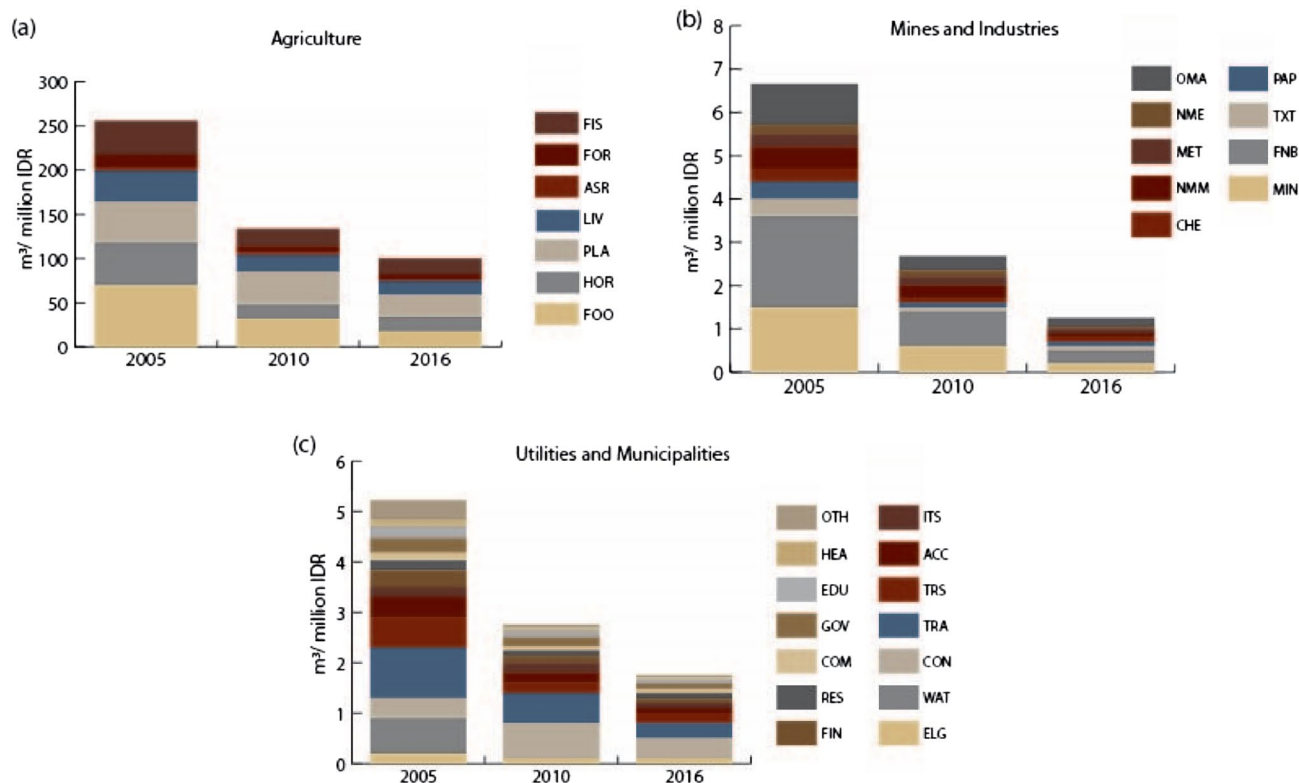
**Fig. 4** The Composition of Estimated Direct Water Intensity (DWI) in each group, 2005–2010. Notes: Agriculture: FOO: food crops; HOR: horticulture; PLA: plantation; LIV: livestock; ASR: agricultural services; FOR: forestry; FIS: fisheries. Mines and Industries: MIN: mining and excavation activities; FNB: food and beverages industries; TXT: textiles industries; PAP: paper and wood industries; CHE: chemical industries; NMM: non-metal minerals processing industries; MET: metal-based industries; NME: non-metal indus-

tries; OMA: other manufacturers. Utilities and Municipalities: ELG: provision of electricity and gas; WAT: water and waste management; CON: construction; TRA: trade; TRS: transportation; ACC: accommodation services; ITS: information technologies (IT) services; FIN: finance services; RES: real estate; COM: company services (consultation); GOV: public governance; EDU: education services; HEA: health services; OTH: other services

continued to decline successively from 4.3 m³/million IDR in 2005 to 1.8 m³/million IDR in 2010 and 0.7 m³/million IDR in 2016 (Fig. 4b). The DWI with the highest proportion in this sector comes from the FNB sub-sector because this industry scale is the largest in Indonesia.

**Utilities and municipalities** Although the DWI in the utility and municipality sectors is low compared to the other commodity groups, such as agriculture and industry, it is interesting to understand the water intensity pattern in their subsectors. The efficiency improvements in these groups are assumed to be relatively lower compared to the other mentioned sectors, as technology development is not as industrious as in the industry or even the agricultural sector. It can be seen from the DWI in this group that it decreased at a lower rate compared to agriculture and industries (Fig. 4c).

In the utility group (ELG), for example, which included gas and electricity generation and distribution, the DWI from 2005 to 2016 did not experience a significant decline, as seen in the agriculture and industries group sector. The DWI

for ELG decreased from 0.17 m²/million IDR in 2005 to 0.13 m³/ million IDR and 0.09 m3/million IDR in 2010 and 2016. The municipalities group sector experienced a higher increase in efficiency compared to the ELG sector. Overall, DWI for this sector group is estimated to have reached 5.04 m3/ million in 2005 and then gradually decreased to 2.66 m³/ million IDR in 2010 and to 1.69 m³/million IDR in 2016. The most significant increase in efficiency comes from the water and waste sector treatment, where the DWI in 2005 reached 0.69 m³/million IDR in 2005 and then decreased drastically to only reach 0.01 m3/million IDR in 2010 and 2016. This happened because, in 2008, the government passed Law No. 18/2008 regarding waste management. It also changed the paradigm in Indonesia from waste dumping to recycling. Under this law, waste is classified more specifically as follows: (1) household waste, (2) waste that is similar to household waste (including waste from the commercial sector) and (3) specific waste (including waste that is dangerous, toxic or cannot be processed). This law has made waste management more efficient because there has been

a more specific implementation of waste based on its type (Raharjo et al. 2017). This allows more water resources to be saved in Indonesia's waste and water management process.

### Indirect water intensity

The IWI in this study is used to estimate how much indirect water is used by a sector to produce one million IDR of output. As indirect water describes the embodied water along the supply chain of a product, it is also often known as virtual water. The IWI value indicates the amount of intermediate input used and the level of efficiency of the supply chain in the sector concerned.

**Agriculture** When compared to DWI, the intensity of IWI in the agricultural sector is only half, with an estimated value of 127.79 m³/million IDR in 2005, which then continued to decrease to 56.97 m³/ million IDR in 2010 and to 37.55 m³/

million IDR in 2016 (Fig. 5a). What is interesting is that the IWI in the PLA sector has also dominated the total IWI in the agriculture sector group since 2010. This is in line with the conditions of the PLA sector in Indonesia, especially the oil palm sector, whose scale continues to grow because it is needed to meet demand, domestic industry and even the international market.

Indonesia's PLA productivity, however, is relatively low, even when compared to other countries in the Southeast Asian region (Masitah et al. 2022). This is because PLAs in Indonesia are dominated by smallholders who still manage them with conventional technologies. The low efficiency at the smallholder PLA level results in the use of relatively more agricultural inputs compared to other agricultural sectors. It also means that more intermediate input is needed to support the production activities in Indonesia's plantation sectors. This also explains the high level of IWI in the PLA sector when compared to other agricultural sectors.
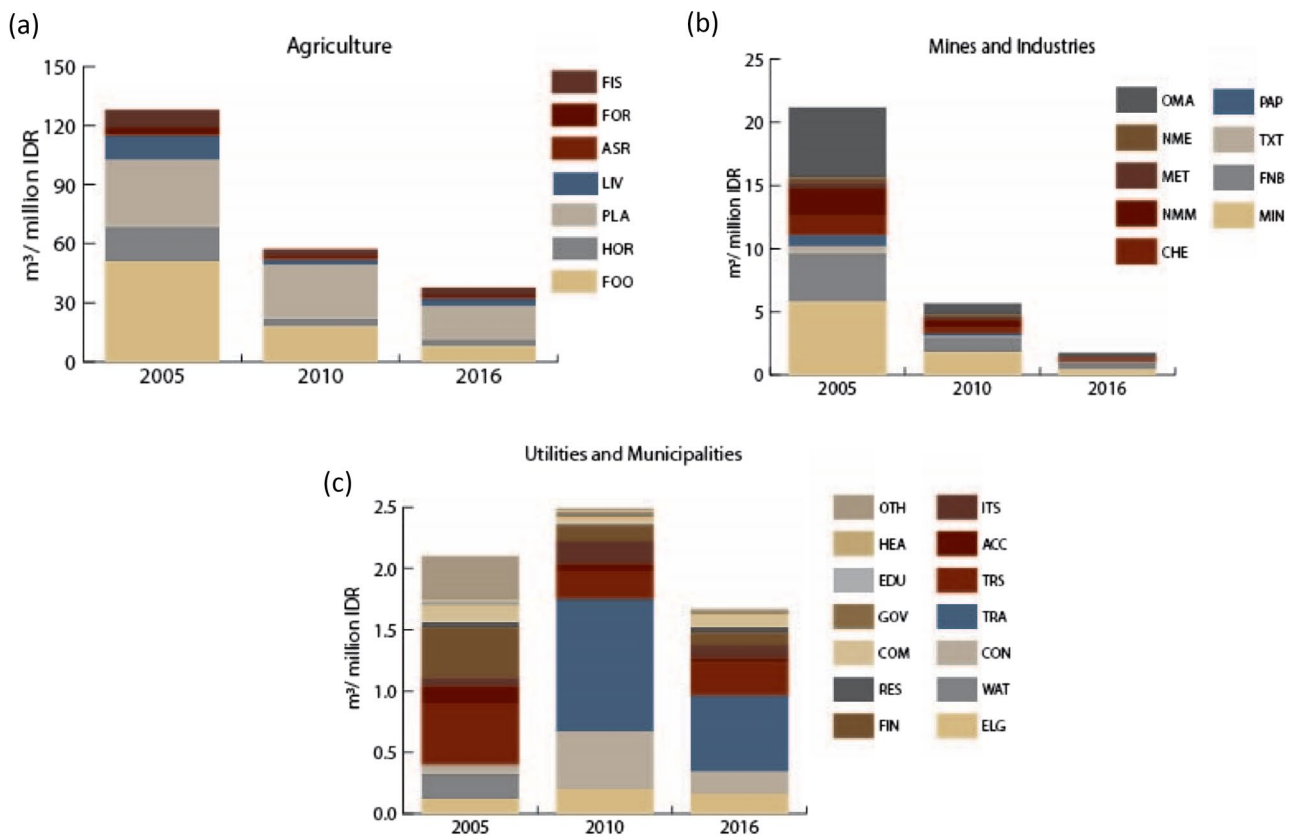


**Fig. 5** The Composition of Estimated Indirect Water Intensity (IWI) in each group, 2005–2010. Notes: Agriculture: FOO: food crops; HOR: horticulture; PLA: plantation; LIV: livestock; ASR: agricultural services; FOR: forestry; FIS: fisheries. Mines and Industries: MIN: mining and excavation activities; FNB: food and beverages industries; TXT: textiles industries; PAP: paper and wood industries; CHE: chemical industries; NMM: non-metal minerals processing industries; MET: metal-based industries; NME: non-metal indus-

tries; OMA: other manufacturers. Utilities and Municipalities: ELG: provision of electricity and gas; WAT: water and waste management; CON: construction; TRA: trade; TRS: transportation; ACC: accommodation services; ITS: information technologies (IT) services; FIN: finance services; RES: real estate; COM: company services (consultation); GOV: public governance; EDU: education services; HEA: health services; OTH: other services

**Mining and industries** In contrast to other sectors, indirect water use in the mining and industrial sector is higher than direct water use. This is because this sector converts raw goods into semi-finished and finished goods, resulting in a long processing procedure and more intermediate inputs. This also resulted in the IWI in this group being higher than its DWI.

If the total DWI in mining ranged from 0.2 to 1.5 $m^3$/million IDR in the 2005–2010 period, the IWI in this sector ranged from 0.46 to 5.79 $m^3$/million IDR in a similar period. As for the industrial sector, IWI in 2005 was estimated at 13.36 $m^3$/million IDR, which then decreased significantly to only 3.82 m3/million IDR in 2010 and 1.31 $m^3$/million IDR in 2016 (Fig. 5b).

**Utilities and municipalities** In the utility and municipalities sector group, there was no significant decline in IWI in the 2005–2016 period. The estimation results for the total IWI in this group were 2.12 $m^3$/million IDR in 2005. It then increased to 2.48 $m^3$/million IDR in 2010 and then decreased again to 1.66 $m^3$/million IDR in 2016 (Fig. 5c).

The most significant increase in IWI was seen in the TRA sector. This result is due to the data definition change of the TRA sector in IO 2005 and afterwards. In 2005, the TRA sector only comprised goods and TRA services that accommodated export and import transactions. That treatment affects the structure of the IO table and restricts the estimation to detecting only the DWI, which is the estimated water intensity in the final demand, not in the intermediate demand. The economic transactions of the TRA sector were calculated and surveyed further after the issuance of Law No. 20/2008 regarding small and medium enterprises when it was realised that the TRA sector offered a significant share. In addition, the TRA sector holds a role in distributing goods from other sectors, including agriculture and industry, to the market. Along with the expansion of its definition, more transactions and activities in the economy are counted in this sector, causing more water intensity that can be quantified in 2010 and 2016.

Compared to the other sectors, the IWI share from the CON sector is quite big. There was also no apparent decreasing trend in water intensity in the CON sector compared with 2005. Total water intensity in 2005 was 0.51 $m^3$/million IDR, and then it shot up to 1.20 $m^3$/million IDR in 2010. In 2016, the water intensity had decreased to 0.56 $m^3$/million IDR. Although lower than in 2010, it was still higher than in 2005, so there are still inefficiencies in water use in this subsector. This IWI is also higher than its DWI. However, the difference is not huge. This trend is quite different from the global trend, especially if compared with the developed countries, in which the gap between DWI and IWI in the CON sector is significant. The DWI is generally very small compared to IWI because they have CON

technology capable of reducing direct water use to facilitate CON, prefabrication and washing concrete or on-site ablution blocks. In those instances, indirect water dominates the water intensity due to the large amounts of materials used in the services, fixtures and fittings—especially in larger high-rise buildings with complex services such as elevators, air conditioning and fire systems (McCormack et al. 2007). This estimation strengthens the allegation that the application of more advanced technology in Indonesia's municipalities is still relatively low.

## Water footprint

In terms of water intensity, as explained in section "Water Intensity", Indonesia increased its efficiency in water use while producing goods and services between 2005 and 2016. Ideally, the quantity of water used will decrease as efficiency increases. However, there are also conditions where increases in efficiency trigger an increase in demand. This condition is known as the *Jevons paradox* (Polimeni et al. 2012). This situation happens a lot in natural resources, including water usage. For this reason, it is also important to estimate the quantity of water consumed by each sector in the economy to see which sectors tend to experience the Jevons paradox.

There are increases in total produced output in almost all sectors of Indonesia's economy from year to year, except for the water and waste development sector. If there are no increases in efficiency, then the quantity of water consumed will also increase. However, the quantity of water used to produce products is expected to be reduced with increases in efficiency so that it stagnates or even decreases. In this study, the quantity of water consumed in the production process is estimated by calculating the Gross Water Footprint (GWF). By looking at the estimation results, it can be seen that several sectors are still experiencing increases in their water footprints despite the increases in water use efficiency. This indicates that these sectors tend to continue to experience rapid increases in water demand from year to year. Table A1 in the Appendix describes the estimation result for the water footprint in this study.

In the agricultural sector, increased GWF is detected in all sectors except food crops (FOO) and forestry (FOR). The plantation (PLA) sector has the highest total GWF compared to other sectors, followed by the livestock (LIV), fisheries (FIS), and horticulture (HOR) sectors. Although these subsectors experienced declines in GWI from 2005 to 2016, their GWFs tended to increase. This is most likely due to the massive expansion of the total cultivated areas for those subsectors. It is a common practice, especially in developing countries, that producers boost their production at higher rates than the efficiency improvement rates of the sectors to achieve certain production targets. This

also makes economic crops more prone to experiencing the Jevons paradox (Wang et al. 2020).

Commercial plantations in Indonesia—especially palm oil—have a very important economic role. The country is the largest producer of palm oil in the world. Exports of processed palm products continuously contribute to state revenue. Due to the increasing national and global demand for biofuels, palm oil companies continue to strive to increase their production. The Indonesian Palm Oil Association (GAPKI) claims that they are targeted to achieve a national crude palm oil (CPO) production of 60 million tons in 2030 (Musta'idah 2013); the value of CPO production in the 2017–2021 period only reached an average of 45 million tons. With low palm oil yields, especially in smallholder plantations, extensification, and intensification efforts are needed for this commodity, which will undoubtedly lead to increased production factor demands, including water.

Indonesia also has a vision to achieve self-sufficiency in meat, even though Indonesia's consumption of animal protein is still very low. In addition, to meet the needs for animal protein and optimise the potential of Indonesia's vast territorial waters as an archipelago, the country continues to increase its production target in aquaculture, resulting in the use of more water to fulfil its production target.

Apart from meat and fish, the country's mission is to reduce its high import of horticulture products, especially fruits and vegetables. The government wants to transform the horticulture sector into an agribusiness sector that is more competitive and integrated with the agro-industry sectors to increase income from this subsector. For the last five years, the Indonesian government has tried to increase horticulture production by creating more farms and developing more horticulture-integrated areas and sites in villages (Kementan 2023).

A similar trend also occurred in the municipalities and services group. Even though the water intensity of this sector is not very high, there has not been a major decrease in water intensity, especially from 2010 to 2016, indicating no significant increase in efficiency related to water use. Apart from that, urbanisation has increased with Indonesia's growing economy, thus encouraging the expansion of settlement development areas along with various infrastructure developments. This increase in economic activity throughout Indonesia resulted in an increase in GWP in almost all subsectors in the municipalities and services sector, indicating that there was a tendency to increase the quantity of water used in this sector over the decade. This is also in line with the research of Warziniack and Brown (2019), which states that population is the most important driver of increased water use because population growth is accompanied by the development of residential, commercial, and industrial areas designed to meet community needs.

Heidari et al. (2021) stated that there is a strong link between an increase in the quantity of water demanded in the municipality sector and an increase in the annual average temperature in an area. If people are not aware and no adaptation action is taken, there will be an increase in the use of water to help reduce temperatures indoors and outdoors. Indonesia is a tropical country with a fairly high annual average temperature. Based on calculations from the Indonesian Meteorology, Climatology and Geophysical Agency (BMKG), the normal air temperature for the period 1991–2020 in Indonesia was 26.8 °C, and the average air temperature in 2022 was 27.0 °C (BMKG 2023). The agency estimates that the temperature will continue to increase by around 0.03 °C every year (BMKG 2019). This temperature increase is likely to increase the amount of water used in the municipalities and services sector.

## Virtual water footprint/trade

The hidden water flow that comes with the international trade of commodities is described as the VWF or the virtual water trade. A positive VWF value indicates that a country tends to import more water-intensive commodities. A positive VWF has a favourable meaning because it is assumed that a country can conserve water resources by choosing to import commodities that require a lot of water consumption (Hoekstra 2003). However, this also indicates a tendency for imports to increase and a dependence on other countries that produce these water-intensive products. A problem will arise if the exporting countries experience water stress; they may reduce or even stop supplying the products in the market. For this reason, sectors with high VWF values need to increase their efficiencies so that they are not too dependent on other countries.

The result of this virtual water trade is also shown in Table A1 in the Appendix. Based on the estimation result, apart from GWF, which is experiencing an increasing trend in the HOR, PLA, and LIV sectors, these sectors are also experiencing positive VWFs that tend to increase every year. This also indicates a significant dependence on imports in these sectors. Nearly half of Indonesia's total imports of HOR commodities and several PLA commodities (including fruits and vegetables) come from China, and another 10% comes from other Asian countries such as India and Thailand. Regarding LIV commodities, because production costs for the LIV business in Indonesia are still very high, it continues to import meat and processed products in the sector from other countries, especially from Australia (BPS 2020). This shows that the demand for products in these sectors is high, but because it is less efficient, Indonesia still needs to meet demand from abroad. These results also indicate that more effort is needed to improve efficiency in these sectors.

Although not as high as the agricultural sector, several sectors in the municipalities and services group also experienced an increase in positive VWF and GWF; this happened in the IT and company services and social and health services sectors. However, the value is very small, ranging from 1 to 4 million m³ annually.

## Discussion and policy implication

Based on the estimation results of water intensity, water footprint, and virtual water trade, sectors that require special attention related to water consumption can be decided. Criteria for selection are sectors that have high water intensity, are experiencing an increasing trend in water footprint, and have positive and increasing value in virtual water trade. Five sectors with the highest water intensity are selected as sectors with high water intensity from each group. This high-water intensity represents the efficiency level of water consumption, as more water is needed to produce one monetary unit of its product. The increasing water footprint indicates that a sector consistently consumes more water. In addition, a positive water footprint describes the conditions in which the sector relies on 'water imports' to meet domestic demand.

The horticulture (HOR), plantation (PLA), and livestock (LIV) sectors meet all of those criteria. These sectors need special attention regarding their water consumption (Table 3). The high value in water intensity, water footprint and virtual water trade indicates that these sectors are inefficient, despite their high demand. Based on estimations, there were efficiency improvements in water intensity from 2005 to 2016, but the water use efficiencies are still insufficient to cover the rapid growth of demand in these sectors. As a result, these sectors keep increasing water consumption while also doing some importation. These three sectors need to increase their effectiveness.

Because they are included in the agricultural commodity group, one of the important ways to overcome this problem is by applying more efficient agricultural technology. This includes preharvest and postharvest technology, as well as technology related to water consumption.

When a country cannot meet its water demand domestically, 'water import' often becomes a way for that country to achieve water sufficiency. However, this method is not sustainable for self-sufficiency because it can negatively impact the economy. This is because most countries that export water-intensive goods are developing countries that are also vulnerable to water stress. In the study of Yang et al. (2003), a trend was found showing that many countries reduce the export of water-intensive commodities dominated by agricultural products and choose to fulfil their domestic needs first. That trend results in higher prices for those products. Thus, countries that are too dependent on imports and still have to meet their needs for these commodities through imports must increase their spending to account for the increase in the 'water budgets' for these commodities.

It is very unfortunate because, with the vast potential of Indonesia's agriculture, Indonesia can optimise domestic production without being too dependent on imported horticulture and plantation commodities. The difficulty is that Indonesian agriculture is dominated by smallholder farms where the production processes are still carried out using simple and conventional methods. For example, palm oil is Indonesia's superior product from the plantation sector, and it is one of the sectors that contributes a lot to state revenues. As the superior product, this sector has a very high production target. Unfortunately, half of Indonesia's palm oil plantations are smallholders, and more than half of these are technically inefficient. Because the demand for this commodity is very high, the way to boost production is to continue to increase the area of land and the number of other inputs, such as fertiliser and water (Abdul et al. 2022).

Other plantation sectors, such as cocoa and coffee commodities, face more serious conditions. Even though Indonesia is the world's sixth-largest cocoa bean producer (Kemenkoekon RI 2021) and the fourth-largest coffee producer (Tiofani 2022), it still imports many of these commodities. Again, this is due to inefficiencies along the sectoral supply chain in the sector. On the on-farm side, the majority of plantations in Indonesia are small-scale communities with minimal land management technology and inefficient resources. On the industrial readiness side, many domestic industries have only been able to process into semi-finished goods, making the country often export raw or semi-finished goods but still have to import finished and processed goods (Ruslan and Prasetyo 2021).

Matters are more complex in the horticulture (HOR) and livestock (LIV) sectors because these commodities face food loss problems. Due to the rapid increase in domestic demand for these commodities, farmers try to boost production, which increases the demand for agricultural inputs, including water resources. Problems then arise because of increasing uncertainties about the weather and the poor storage systems in the agricultural sector. When there is an increase in temperature or a long dry season, LIV and HOR commodities need more water. Because there is no proper storage system, many HOR products—especially fruits and vegetables—wither or are damaged during distribution in the postharvest stage. In Indonesia, LIV is usually transported to markets or buyers alive, so many are already sick or even die during transport. This high level of food loss indicates very serious inefficiencies in the supply chains of these sectors. It is also why Indonesia continues to import in these sectors. Based on the estimates in this study, Indonesia has used many water resources to achieve production targets. However, it continues to import in quantities that are inclined to

**Table 3** Checklist summary on the estimation of water intensity, water footprint and virtual water

| No. | Commodity group | Sectors/code | Highest water intensity in each group* | Increasing trend in water footprint | Positive virtual water footprint | Notes |
|---|---|---|---|---|---|---|
| 1 | *Agriculture* | Food Crops/*FOO* | X | | X | Inefficient, reliance on import |
| 2 | | Horticulture/*HOR* | **X** | **X** | **X** | Inefficient, increasing demand trend, reliance on import |
| 3 | | Seasonal and annual plantation/ *PLA* | **X** | **X** | **X** | Inefficient, increasing demand trend, reliance on import |
| 4 | | Livestock/ *LIV* | **X** | **X** | **X** | Inefficient, increasing demand trend, reliance on import |
| 5 | | Agricultural Services/ *ASR* | | X | | Increasing demand trend |
| 6 | | Forestry/ *FOR* | | | | |
| 7 | | Marine and Fisheries/ *FIS* | **X** | **X** | | Inefficient, increasing demand trend |
| 8 | *Mines and Industries* | Mining/ *MIN* | X | | | Inefficient |
| 9 | | Food and Beverages/ *FNB* | X | | | Inefficient |
| 10 | | Textile Industries/ *TXT* | | | | |
| 11 | | Paper and Wood Industries/ PAP | | | | |
| 12 | | Chemical Industries/ *CHE* | X | | X | Inefficient, reliance on import |
| 13 | | Non-Metal Minerals/ *NMM* | X | | X | Inefficient, reliance on import |
| 14 | | Metal-Based Industries/ *MET* | | | | |
| 15 | | Non-Metal Industries/ *NME* | | | X | Inefficient reliance on import |
| 16 | | Other Manufactures/ *OMA* | X | | X | Inefficient, reliance on import |
| 17 | *Utilities and Municipalities (including Services)* | Provision of Electricity and Gas/ *ELG* | | X | | Inefficient, increasing demand trend |
| 18 | | Water and Waste Management/ *WAT* | | | | Inefficient |
| 19 | | Construction/ *CON* | **X** | **X** | | Inefficient, increasing demand trend |
| 20 | | Trade/ *TRA* | **X** | **X** | | Inefficient, increasing demand trend |
| 21 | | Transports/ *TRS* | **X** | **X** | | Inefficient, increasing demand trend |
| 22 | | Accommodation Services/ *ACC* | **X** | **X** | | Inefficient, increasing demand trend |
| 23 | | Information and Technologies/ *ITS* | | X | X | Increasing demand trend, reliance on import |
| 24 | | Financial Services/ *FIN* | X | | X | Inefficient, rely on import |
| 25 | | Real Estate/ *RES* | | X | X | Increasing demand trend, reliance on import |
| 26 | | Company Services/ *COM* | | X | X | Increasing demand trend, reliance on import |
| 27 | | Public Governance/ *RES* | | X | | Increasing demand trend |

**Table 3** (continued)

| No. | Commodity group | Sectors/code | Highest water intensity in each group* | Increasing trend in water footprint | Positive virtual water footprint | Notes |
|-----|-----------------|--------------|----------------------------------------|-------------------------------------|----------------------------------|-------|
| 28 | | Educational Services/ EDU | | X | X | Increasing demand trend, reliance on import |
| 29 | | Social and Health Services/ HEA | | X | X | Increasing demand trend, reliance on import |
| 30 | | Other Services/ OTH | | | | |

*1–5 sectors in each group are selected based on the highest average of GWI

increase annually. This is, of course, a waste of resources for the country.

Indonesia also needs to be wary of other sectors with high water intensity and increasing water footprints that have not yet shown positive and increasing values in virtual water as it consistently shows the inefficiency condition but high water demand. These sectors include Marine and Fisheries (FIS), Construction (CON), Trade (TRA), Transportation (TRS) and accommodation (ACC). The sectors are relatively inefficient and continue to experience increasing trends in their quantity of water footprints but do not import thus far. If there is no increase in efficiency related to water consumption, producers in these sectors may choose to import raw materials and finished products to accommodate the resource insufficiencies in the country. It is a national trend that Indonesia is trying to boost the production of those four sectors. The FIS sector is the backbone of the country's blue economy, and the government also wants to boost this sector to fill the productivity gap in the livestock sector (Sari and Muslimah 2020). The TRA is also important as it includes all small and medium enterprises that dominate the labour market (BPS 2022). While the CON and TRS keep increasing because Indonesia is very concerned about speeding up all infrastructure development throughout the country, especially outside the Java area (Faradis et al. 2020). Based on the estimation results in this study, water use by these four sectors has continued to increase. Hence, it is necessary to accelerate efficiency improvements to offset the high production rate and resource demand from these sectors.

## Conclusion

This study aims to estimate the detailed demand for water in each sector of Indonesia's economy by utilising the concept of water footprint—the quantity of water consumed to produce output. This estimation is made to accommodate the absence of detailed calculations of water consumption by sector in Indonesia. The estimation is carried out by using information related to the economic structure obtained from the national IO table. The information is then used to

estimate the water intensity (water consumed to produce one million IDR of output) and the water footprint.

Based on the results of the water intensity estimation, it appears that the agricultural commodities sector has the highest intensity. Water intensity is an indicator that also shows the level of efficiency of a sector in consuming water. In this regard, it is notable that the PLA, LIV and HOR sectors tend to be more inefficient than other sectors in Indonesia.

As the water intensity shows the trend of efficiency improvement, the amount of sectoral water consumption can be represented by quantifying the water footprint. After calculating the sectoral water footprint, the trend of Jevon's paradox in water consumption was found in several sectors.

It is generally assumed that resource consumption tends to decrease as efficiency improves. However, this is not the case in several sectors in Indonesia. The increase in efficiency, as evidenced by the gradual reduction in water intensity, does not appear to be hindering the increase in the water footprint in several sectors of the agricultural group and communities. This shows that the efficiency improvement in these sectors is still relatively low and has not been able to cope with the rapid increase in demand for these commodity groups.

Even though Indonesia has abundant water resources, based on the estimation results, there is also a positive and increasing VWF detected in several sectors. This VWF value shows that Indonesia imports a lot of water-intensive products. Although it is not a problem in the short and medium terms, if it continues to be carried out in the long term, Indonesia's import expenditures may increase because it indirectly has to pay the 'water budget' on these commodities.

Efficiency improvements are important to maintain the sustainability and economic performance of water resources. It is very unfortunate if a country that is abundantly endowed with water resources cannot properly utilise these resources, experiences waste and continues to increase spending on imported water-intensive products, as has happened in the PLA, HOR and LIV sectors. Water and economic resources will be wasted if the problems in these sectors are not addressed, and efficiency improvements are not quickly

established. These include providing better harvest and post-harvest technologies, especially for smallholder producers, and reducing food loss by improving distribution and storage systems for agricultural commodities.

In addition to the three sectors mentioned above, other sectors that experience high levels of water intensity and water footprint also need attention. More efficient technologies are needed to forestall large increases in imports of raw materials and finished products in these sectors so that Indonesia can minimise the possibility of greater waste in its economy.

In the future, this study can be further expanded by estimating the water footprint by province, considering the water supply in Indonesia is unevenly distributed. It will also be interesting to estimate the green and grey waters and total water footprint when factoring in food loss and food waste, which are also other main resource waste in the country.

## Declarations

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