Analyzing the relationship between water pollution and economic activity for a more effective pollution control policy in Bali Province, Indonesia

Saroj Kumar Chapagain (✉ saroj@unu.edu)

United Nations University Tokyo: Kokuren Daigaku <https://orcid.org/0000-0002-7348-2085>

Geetha Mohan

United Nations University Tokyo: Kokuren Daigaku

Andi Besse Rimba

Shibaura Institute of Technology - Toyosu Campus: Shibaura Kogyo Daigaku

Carolyn Payus

United Nations University Tokyo: Kokuren Daigaku

I Made Sudarma

Udayana University: Universitas Udayana

Kensuke Fukushi

United Nations University Tokyo: Kokuren Daigaku

Research Article

Keywords: Biochemical oxygen demand (BOD), Bali, Environmentally extended input–output (EEIO) modeling, Direct pollution, Water policy, Water pollution

Posted Date: July 12th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-604424/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Sustainable Environment Research on January 11th, 2022. See the published version at <https://doi.org/10.1186/s42834-021-00115-6>.

Analyzing the relationship between water pollution and economic
activity for a more effective pollution control policy in Bali Province,
Indonesia

Saroj Kumar Chapagain^{1*}, Geetha Mohan^{1,2*}, Andi Besse Rimba³, Carolyn Payus^{1,2,4}, I Made
Sudarma⁵, and Kensuke Fukushi^{1,2}

¹United Nations University, Institute for the Advanced Study of Sustainability (UNU-IAS), 5-53-
70, Jingumae, Shibuya-Ku, Tokyo, 150-8925, Japan

²Institute for Future Initiatives, University of Tokyo, 7-3-1 Hongo, Bunkyo-Ku, Tokyo, 113-
0033, Japan

³Shibaura Institute of Technology, 3-7-5 Toyosu, Koto-Ku, Tokyo, 135-8548, Japan

⁴Faculty of Science & Natural Resources, Universiti Malaysia Sabah, 88400, Kota Kinabalu,
Sabah, Malaysia

⁵Centre of Environmental Research, Udayana University, PB Sudirman, Denpasar, Bali,
Indonesia

*Correspondence: saroj@unu.edu; geetha.mohan@unu.edu

Abstract

An adequate water supply is essential for the continued and sustainable growth of the Balinese economy. In addition to mounting water demand, Bali's water supply has been compromised by high levels of water pollution. Despite being paid great attention, Bali's earlier efforts to control water pollution yet to prove effective, mainly owing to their reliance on traditional methods and regulations that focus on water pollution being linked to discrete sets of economic activity (e.g., processing industries, livestock farming, and hotels). However, all economic sectors are interconnected through supply chains; thus, water pollution is the combined result of all sectors' environmental performance. Therefore, determining the structural relationships between water pollution and economic activity serves as an important basis for more effective forms of pollution control for the Balinese economy. In this study, accordingly, we employed an environmentally extended input–output model to establish the links between water pollution and the production processes of the entire economy. Using biochemical oxygen demand (BOD) as a proxy for water quality in our analysis, we estimated that 246,868 tons of BOD were produced from Bali's economic activity in 2007. Further, we identified the chief BOD-emitting sectors and found that intermediate demand and household demand were the major causes of BOD discharge in the economy. Utilizing supply chain relationships, we also accounted for the indirect role of each sector in total BOD emissions. Moreover, we categorized the sectors into four groups based on their direct and indirect BOD emission characteristics and offered appropriate policy measures for each group. Managing demand (i.e., lowering household consumption and exports) and shifting input suppliers (i.e., from polluters to non-polluters) are effective measures to control pollution for Categories I and II, respectively; clean production and abatement is advised

for Category III; and a hybrid approach (i.e., demand management and abatement technology) is recommended for Category IV.

Keywords: Biochemical oxygen demand (BOD), Bali, Environmentally extended input–output (EEIO) modeling, Direct pollution, Water policy, Water pollution

1. Introduction

Global water resources are under immense pressure owing to increases in water demand that are due to population growth and expanded industrial and economic activity. The stress has been further exacerbated by increasing water pollution [1, 2]. Flörke et al. [3] reported that the global withdrawal of domestic and industrial water increased by 77.7% with 300–1,345 cubic kilometers (km^3) withdrawn over the last six decades (1950–2010); of the extracted water, 88% was ultimately returned to the system as wastewater with limited treatment. The situation is a serious concern in the Asia–Pacific region, which is undergoing rapid economic growth. Consequently, the region’s natural environment is being distressed by the consumption of huge amounts of water, the release of waste and wastewater, and the expansion of pollution-prone industries [4].

Bali, Indonesia, a famous global tourist destination in the Asia–Pacific region [5, 6], has undergone rapid economic growth over the last three decades [7]. The Balinese economy is traditionally supported by agriculture; however, it has recently become dominated by the tourism sector [8]. In 2018, tourism (i.e., accommodation and food services) accounted for 23.34% of Bali’s gross regional domestic product (GRDP), while agriculture, forestry, and fisheries accounted for 13.81% of its GRDP [6]. Bali’s population was reported to be 4,380,800 as of 2020 with an average annual growth rate of 1.24% (2010–2018) [6, 9]. Rapid economic growth, population growth, and poor water management will likely cause more serious water shortages in

the future [10]. Despite its substantial potential for natural renewable water, Bali's water supply is compromised because of an elongated coastland, lower groundwater potential, and a high population density (FAO 2003 as cited in Strauß et al. [5]). By 2025, water consumption is projected to expand by 70% [5, 11]. Water shortages are reported to reduce food production and employment on the island, while both tourism and agriculture rely on an adequate water supply [11, 12].

Environmental degradation and pollution have put Bali's water resources at significant risk [10, 11]. Water quality has been affected by recent economic development. For example, there is a strong relationship between the existence of water pollutants, such as organic substances (biochemical oxygen demand (BOD)) and fecal matter (*Escherichia coli*), in river water and population density. Similarly, built-up areas, which have been increasing recently, have impacted the river water quality negatively by elevating heavy metals (i.e., nickel and lead) and turbidity [13]. Suteja et al. [14] reported that the two major rivers—namely, the Badung and Mati Rivers—were the primary source of chromium deposits in the river estuary of Benoa Bay. A significant amount of water pollutants is reportedly discharged in water bodies because of intensive agricultural practices, including the excessive use of fertilizers and plant protection chemicals [15]. Nitrate and phosphate contamination prevails in all the rivers, although the contamination levels vary depending on the river and season. The highest loadings of nitrates and phosphates were reported as 4.387 and 6.980 tons per day, respectively, in the Mati River, which drains into Benoa Bay, in the dry season, thereby causing the water quality to exceed the standard for marine biota [16, 17]. River water, namely, that of the Ayung and Badung Rivers, is the major source of drinking water and irrigation. Meeting water quality standards, such as having a BOD of 2 and 12 milligrams (mg)/liter (L), respectively, for class I (i.e., potable water

supply) and class IV (i.e., irrigation use), as stipulated in the water quality management and control measures of the Indonesian Government Regulations number 82 of 2001 [18], is challenging.

The island of Bali operates two centralized wastewater treatment plants with a total capacity of 61,000 (51,000 + 10,000) cubic meters (m^3) per day [10, 15] as well as some community-based decentralized wastewater treatment systems with limited capacities [19]. Since the current treatment capacity is less than 10% of the total urban wastewater production (642,000 m^3/day , as estimated in 2012) [10], a vast portion of wastewater from households, industries, hotels, restaurants, business, and complexes, and waste and runoff of agriculture and livestock directly drains into nearby canals, rivers, and ocean [11, 15, 17]. The direct discharge of toxic industrial wastes into the river system that ultimately reaches the beaches has drawn significant attention [14, 17]. Several initiatives have been undertaken by government and private organizations; nevertheless, these have not been enough to yield significant outcomes. Most studies have focused on determining the water quality state, links with changes in land use, and particular sectoral or sub-sectoral activities (e.g., textile industries and hotel businesses) [14–16, 20]. However, the environmental performance of an economy is governed by all sectors, which are interrelated through supply chains. Analyzing the relationship between economic activity and water pollution is increasingly considered a useful approach to managing water resources [21, 22].

Generally, the pollution caused by economic activity is positively related to output [23]. The economy of a country or region comprises several sectors, each of which receives inputs from its own and other sectors by delivering outputs. Analyzing the inter-sectoral relationships along with resource use (inputs) and pollutant emissions allows us to calculate resource use (e.g.,

energy, water, and land) and manage the environment (e.g., waste) [24]. Such an analysis identifies sectors as either pollution sellers, buyers, or both, which is essential for prioritizing pollution control policy [25]. To apply this approach, the conventional input–output (I–O) table is extended to include environmental parameters (e.g., water pollutant emission intensity), which are useful in evaluating the impact of production process (i.e., in the present or the future with changes in the economy) on the water environment [21, 26–28].

In this study, we employed the environmentally extended input–output (EEIO) model to tie water pollution together with Bali’s economic activity. Broadly, our objective is to recommend policies for managing Bali’s water pollution in context of its rising economy. The specific research objectives are to analyze the links between various economic activities and BOD emissions, estimate direct and indirect sectoral BOD emissions, classify sectors into comprehensive groups based on their BOD emission characteristics, and provide pollution control management strategies.

2. Study area

Bali, a province of Indonesia (Fig. 1), covers a total area of 5,620 square kilometers (km²), or 0.30% of the total land area of the Indonesian archipelago. The island lies entirely within the tropics and possesses a tropical marine climate. The average annual precipitation is approximately 17,411 millimeters (mm) [6]. Rivers, groundwater, and springs—the major freshwater resources—are not uniformly distributed across the region. Owing to the incidence of major rainfall (75%–80%) during November through April, maintaining an adequate water supply for the agriculture and tourism sectors is a challenge during the dry season [29].

Fig. 1 Map depicting the location of Bali Province

In 2018, the Balinese economy reportedly grew by 6.35%. The contribution of various sectors to the GRDP for 2018 is demonstrated in Fig. 2 [6]. The accommodation and food service sector's activities under tourism provide the dominant share of GRDP, followed by the agricultural, forestry, and fishery sector. The contribution of the agricultural, forestry, and fishery sector has declined in recent years. The Balinese economy has shifted from a primary to a tertiary economy with the recent growth of the tourism sector [6]. Other sectors, such as the transportation and construction industries, have a dominant share of the GRDP, accounting for 9.5% and 9.4%, respectively. These sectors have reported increasing growth in the GRDP owing to the expansion of the tourism sector. In total, 382 companies representing large (100 or more employees) and medium (20–99 employees) industries were in operation in Bali in 2017; of these, the food and beverage industry had the greatest share of the GRDP [6].

Fig. 2 Sectoral distribution of the gross regional domestic product (GRDP) of Bali, 2018

3. Materials and methods

3.1. Conventional I–O table

In an economy's production process, each sector requires inputs from its own and other sectors to produce goods and services. The concept of describing the inter-linkages between sectors in an economic system was introduced by the economist Wassily Leontief. His I–O model is conventionally used to describe the interconnections between sectors [30]. Table 1 presents an example of an economy's flow of goods and services, visualizing the interdependence between the sectors [31]. The rows represent the proportion of output that each sector sells (seller) to other sectors (purchaser); the columns represent the proportion of products and services required (purchased) by each sector from other sectors as inputs to meet total output. Apart from intermediate demand, an I–O table indicates the quantity of products and services

consumed by households, the government, and exports (final demand) as well as the amount of products and services that sectors import (imports) and the compensation paid to labor (value added). I–O tables are formulated based on the data for a particular economic area, nation, or region [32].

Table 1 Schematic representation of a conventional I–O table.

An I–O table comprises a set of linear equations. The basic equation of Leontief’s model describes the inter-sectoral relationships in an economic system [33]. It depicts the fact that total output is equal to the amount used internally used by the system as intermediate consumption plus the amount consumed by the final customers (Leontief as cited in Nguyen [21]).

$$x_i = \sum_{j=1}^n x_{ij} + d_i \quad (1)$$

where x_{ij} is intermediate consumption [21], d_i is the final demand for goods by each sector, and a_{ij} is the technical coefficients of production, which are described as the amount of products that the j^{th} sector purchases from the i^{th} sector to produce one unit of (j^{th}) output.

$$a_{ij} = \frac{x_{ij}}{x_j} \quad (2)$$

Eq. (1) can be rewritten as follows after incorporating a_{ij} :

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

Converting the equation into matrix notation for the entire economy yields the following:

$$x = Ax + d \quad (4)$$

A represents the $n \times n$ technical coefficient matrix with the element (Table 1).

Solving for x , we obtain the total production delivered to fulfill final demand as follows:

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

168 where I denotes an identity matrix and $(I - A)^{-1}$ is the Leontief inverse matrix. Let α_{ij} represent
 169 the elements of the Leontief matrix. Subsequently, the gross domestic output of sector i , x_i , can
 170 be expressed as follows:

$$x_i = \sum_{j=1}^n \alpha_{ij} d_i \quad (6)$$

171 3.2. EEIO model

172 I–O tables show the flows between sectors and frame their interrelationships. An EEIO
 173 analysis, an extension of Leontief's I–O model [32], is a simple and robust method for assessing
 174 the links between economic activity and environmental impact [34]. EEIO quantifies the
 175 environmental pressure along the supply chain while assuming an unchanged production
 176 structure [35].

177 The release of water pollutants is usually expected to be linearly proportional to the size of
 178 sectoral outputs [21, 23]. We assume $\mathbf{PI}$ as pollution intensity and define it as the amount of
 179 water pollutants released to produce one unit of output (in monetary terms) for a sector. Its
 180 elements, PI_i^y , denote pollution intensity related to the y^{th} water quality parameter for sector i in
 181 a particular year. The $y \times n$ matrix, $\mathbf{PI}$, is the pollution intensity matrix. The pollution load ($\mathbf{PL}$)
 182 can then be computed using Eq. (7).

$$PL = PIx \quad (7)$$

183 The PL for the k^{th} parameter for sector i , PL_i^k , is expressed as follows:

$$PL_i^y = PI_i^y x_i \quad (8)$$

184 Substituting the value of x_i from Eq. (6) into Eq. (8) yields the following:

$$PL_i^k = PI_i^y \sum_j \alpha_{ij} d_i \quad (9)$$

The PL of sector i is the amount released to satisfy all production in this sector (x_i), including both the intermediate ($\sum_j a_{ij}x_j$) and final demand (d_i).

3.3. Water pollutant emissions

Each economic sector acts as both a supplier and receiver of inputs in the economy's production process. Based on their roles, the emissions of water pollutants from sectoral activities can be distinguished into two categories: direct (i.e., a source of emissions) and indirect (i.e., a cause of emissions). Direct emissions (DiE) are defined as the amount of water pollutants that are directly discharged by a sector in producing the products required to satisfy all forms of demand (i.e., intermediate demand and final demand) [22]. By contrast, indirect emissions ($IDiE$) are the amount of water pollutants that are discharged by a sector and other sectors to produce the inputs it requires. Unlike direct emissions, the amount of pollutants indirectly emitted by a sector relies heavily on the economic performance of several sectors. This form of pollution is not accounted for by the traditional method; however, pollution control management strategies have recently started incorporating examinations of indirect emissions [22, 36].

Despite being good indicators, direct and indirect emissions still cannot express the flow of pollutants within a single sector [21, 22, 30]. These indicators cannot, for example, quantify the proportion of a sector's direct discharge that is required to meet its own sectoral demand (i.e., sectoral self-pollution) or the level of discharge equal to inter-sectoral demand.

We employed the vertical integrated coefficient method in sectoral pollutant flow analysis [30] and disaggregated the sectoral PLs into five components: (i) a sector's own pollution (OW_i^y) (the amount of y pollutant emitted by sector i to produce its own input); (ii) true forward pollution (TF_i^y) (the amount of y pollutant emitted by sector i to produce products used as inputs of others' intermediate demand); (iii) semi-own pollution (SOW_i^y) (the amount of y pollutant

generated by sector i to produce the inputs for other sectors, which is required to produce inputs that sector i purchases to fulfill final demand); (iv) true backward pollution (TB_i^y) (the amount of y pollutant emitted by other sectors to provide inputs for a sector); and (v) final demand pollution (FD_i^y); (the amount of y pollutant directly emitted by sector i to produce products in fulfilling the final demand of a sector).

3.4. Data sources and EEIO preparation

Two datasets, namely, an I–O table and the sectoral water pollutant emission intensity, are required to perform EEIO modeling. We used a 2007 regional I–O table that originally consisted of 52 economic sectors. The I–O table was revised by removing the sectors that lacked relevant data (such as mining, basic metal industry, and other metal goods industries) and merging the detailed economic sub-sectors into a major sector (e.g., agriculture, fishery, and forestry). Finally, we developed a 16×16 sector I–O table to provide comprehensive results and overcome the limitation of lacking detailed pollutant emission intensities at the sub-sectoral level. The revised grouping of sectors is provided in Supplementary A.

The revised I–O table was further extended by adding the BOD emission intensity for each economic activity as a proxy indicator of overall water quality [37, 38]. The intensity was defined as the amount of BOD discharged per unit of monetary output in millions of rupiah (IDR). The intensities were directly and indirectly collected/derived from various sources. The intensity for the manufacturing sector was obtained from a report on wastewater disposal for Denpasar [39]. The intensities were adjusted into 2007 prices (I–O table); price inflation was overcome through the consumer price index method [40]. We derived the intensities for the selected sectors by calculating the BOD load in kilograms (kg) and taking its monetary output value in 2007. The pollutant load for Sector 1 (agriculture, forestry, and fishery) was derived

from the areas under each sub-sector [41] and the BOD export coefficients for major land use [42–44]. Similarly, the BOD load for Sector 2 (livestock and poultry) was calculated by taking daily livestock’s load (BOD kg/day/cattle) [38] and slaughtering activities (kg/tons of meat) [45] together with Bali’s total number of cattle head and amount of meat produced in 2007 [41]. For hotels and restaurants, we took the total number of visitors and restaurant seats in 2007 [41] and calculated the BOD load per capita (visitor) per day and per restaurant seat [39]. In relation to the service sectors—namely, electricity and drinking water, trading, transport, communication, and financial institutions—that were not direct BOD emitters [36], the intensities from Nguyen et al. [21] were used to examine their role in indirect BOD emissions.

Table 2 presents the EEIO table developed for Bali. Sectoral outputs are expressed in millions of IDR; BOD emission intensity is expressed as kg per millions of IDR.

Table 2 Extended I–O table.

4. Results and discussion

4.1. Sources of and causes for BOD emissions

An estimated total of 246,868 tons of BOD was released in the economy’s production process in 2007. Each sectoral direct BOD load is shown in Fig. 3. Three sectors—livestock and poultry (Sector 2); agriculture, forestry, and fishery (Sector 1); and food, beverage, coffee, and tobacco (Sector 4)—accounted for 99.5% of the total BOD emissions; of these, Sector 2 produced 96% of the total BOD emissions. The BOD amount varied among the sectors because of differences in BOD emission intensity and total output. The results are consistent with earlier findings that indicated livestock plays a major role in freshwater pollution in many parts of the world [38, 44, 46]. The increasing population and the prevalence of many head of cattle—the reported increase in cattle and pig numbers was 3.62% and 11.73%, respectively, from 2017 to

2018 [6]—positioned this sector at the top in terms of water pollution. Conversely, the agricultural land under Sector 1 has recently been declining; however, the heavy use of fertilizers in intensive agricultural farming has kept the sector a leading cause of freshwater pollution. Followed by these two sectors, Sector 4 (food, beverage, coffee, and tobacco) emitted BOD to a greater extent, with a value of 1,894 tons, which notably serves to meet household consumption. The remaining 13 sectors discharged 1,049 tons of BOD, which accounted for only 0.5% of the total BOD emissions.

Fig. 3 Sectoral direct BOD discharge of BOD in the Balinese economy, 2007 (in tons)

The release of water pollutants increases with sectoral output, which is determined by a sector's intermediate and final demand. Intermediate demand reflects how heavily a sector engages in supplying its products to other sectors as inputs. Household consumption, government stock, and exports of a sectoral item determine a sector's final demand. Disaggregating the total PL as per the demand for each sector (Fig. 4) is an effective method of undertaking the appropriate policy measure in controlling water pollution. This figure illustrates that demand factors impact the BOD emissions differently for the various sectors. For instance, intermediate demand was the major cause of BOD emissions in four major sectors, including the top two BOD emitters (Sectors 1–3 and 12). This indicates that these sectors discharged major BOD in producing their products or services for other economic sectors. However, exports were the major cause of BOD emissions (more than 60% of BOD) in the sectors (Sectors 5–9 and 13) that mainly comprise manufacturing industries. This is likely attributable to Bali's adoption of an open economy as exports play an important role in the regional economy [6]. Household demand was the primary cause of BOD (nearly 50%) for Sector 4 (food, beverage, coffee, and tobacco) and Sector 10 (electricity and drinking water), which are both heavily consumed by residents.

Gross stock and changes had negative BOD values for Sectors 4 and 5, indicating that this portion (BOD) was not generated for that year but fulfilled by the stock.

Fig. 4 Percentage of total BOD discharge attributable to each component of each sector's total output

Apart from the direct BOD discharge, we determined indirect BOD emissions by sector (Fig. 5). Sectors 2, 13, 1, and 4 produced as much BOD from other sectors or from themselves to satisfy their inputs. Sector 2 was the chief indirect BOD emitter, accounting for 65% of total BOD emissions; this is likely due to its reliance on its own sector, which is the top direct BOD emitter, for inputs (e.g., baby chicks, calves, fingerlings, and animal feeds). Sector 13 (hotels and restaurants) is responsible for emitting 30% of total BOD owing to its close connection with other sectors—most likely the livestock and agricultural sectors, both major BOD emitters—to operate their business. Importantly, other service and trade sectors show a noticeable contribution to indirect BOD emissions as opposed to their role in direct BOD emissions. This is particularly essential for pollution control planning because the direct emissions of these sectors are often overlooked.

Fig. 5 Indirect BOD discharged relative to total BOD discharge in the Balinese economy, 2007

4.2. Disaggregation of sectoral BOD emissions

An analysis of the sectoral roles in indirect water pollutant emissions has added a new perspective to the conventional approach of direct sectoral water pollution. However, although these are good indicators, these aspects (i.e., direct and indirect pollution) remain unable to fully depict the behavior of sectoral pollution in the economy. To enrich our analysis, we demonstrate the flow of BOD throughout the entire economic sector (Table 3) and its various pollution

components (Table 4). In Table 3, the rows of the matrix indicate the BOD amount that sector i produces to fulfill sector j 's demand. The row sums represent the total BOD directly emitted by sector i in producing products or services to fulfill all forms of the economy's demand (i.e., DiE). The columns of matrix j indicate the purchases made by sector j from sector i during the production process, and the column sums represent the total BOD indirectly emitted by sector j from other sectors (i) in obtaining its input requirements (i.e., $IDiE$). The absence of row data for Sectors 10, 14, and 15 indicates that these sectors do not directly emit BOD (row), while the column values for the same sectors show their indirect role in producing BOD in the economy.

Subsequently, we disaggregate sectoral BOD loads into five components: (i) a sector's own pollution (OW_i^y) (the amount of y pollutant emitted by sector i to produce its own input); (ii) semi-own pollution (SOW_i^y) (the amount of y pollutant generated by sector i to produce the inputs for other sectors, which is required to produce inputs that sector i purchases to fulfill final demand); (iii) true forward pollution (TF_i^y) (the amount of y pollutant emitted by sector i to produce products used as inputs in others' intermediate demand); (iv) true backward pollution (TB_i^y) (the amount of y pollutant emitted by other sectors to provide inputs for a sector); and (v) final demand pollution (FD_i^y); (the amount of y pollutant directly emitted by sector i to produce products in fulfilling the final demand of a sector) (Table 4).

The values vary among the sectors according to their different emission properties. For instance, a high value of TF_i^y for Sectors 1 and 2, pollution seller sectors, indicates that these sectors produce considerable BOD in satisfying intermediate demand. Similarly, Sector 2 is also responsible for producing substantial BOD (24.7% of the total BOD) in fulfilling its own inputs, highlighting the internal dependence of the sector (for their own inputs, i.e., OW_i^y). Other than Sectors 1, 2, and 3, a majority of sectors have a typically high range of TB_i^y , characterizing these

sectors as pollution inducers that cause other sectors to emit BOD to fulfill their input needs. Among these, Sector 13 (hotels and restaurants) has an exceptionally high value, indicating a close linkage between this sector and others and its responsibility for producing a significant amount of the economy's water pollutants. Sector 4 (food, beverage, coffee, and tobacco) is a major pollution inducer because of its processing of raw primary products (i.e., agricultural and livestock products) into edible food items.

Table 3 Matrix of BOD (kg) flow in the economy.

Table 4 Disaggregated sectoral water pollution components with BOD loads (*in tons*).

4.3. Grouping of sectors

To distinguish the sectoral BOD emission behavior and appropriately identify the management plan, we grouped sectors by plotting the percentage of BOD—true forward pollution (TF_i^y)/direct emissions (DiE) and true backward pollution (TB_i^y)/indirect emissions ($IDiE$) (Fig. 6). DiE is defined as the amount of water pollutants (herein BOD) that are directly discharged by a sector while producing the products required to satisfy all forms of demand (i.e., intermediate demand and final demand) [22]. By contrast, $IDiE$ is the amount of water pollutants (herein BOD) that are discharged by a sector and other sectors to produce the inputs that it requires. Generally, high TF_i^y/DiE values indicate that the sectors are liable to produce more water pollutants for other sectors, so the proportion of water pollutants produced for their own sectoral inputs is lower. Conversely, sectors with high $TB_i^y/IDiE$ produce more water pollutants from other sectors.

Figure 6 shows that most sectors fall under Categories I and II. In contrast, there is only one sector in Category III, and none of the sectors belong to Category IV. Category I has less than 50% of both TF_i^y/DiE and $TB_i^y/IDiE$, indicating that the sectors depend heavily on their own

sectoral input and produce more than 50% of the total direct and indirect sectoral BOD discharge in fulfilling their own sector's input demands. As major sources of pollution for their own input requirements, these sectors are characterized as self-polluting sectors. The pollution under this category could be better addressed by the product's final demand. In this regard, policy should focus on measures to lower household consumption and reduce the exports of these sectors.

Fig. 6 Classification of sectors based on their BOD emissions characteristics

Category II is similar to Category I in that $TF_i^y/DiE < 50\%$ but has a high $TB_i^y/IDiE$ (i.e., more than 50%). In addition, by producing a large amount of BOD in fulfilling their own input requirements, these sectors indirectly produce a higher amount of BOD (more than 50% of the total sectoral indirect BOD emissions) from other sectors. Apart from self-polluters, these sectors are characterized as pollution inducers. Sectors such as Sectors 14 and 15 lie to the right bottom because of the lack of their own direct BOD discharge (DiE is 0); however, these sectors indirectly cause a significant amount of BOD from other sectors. In terms of the pollution control perspective, there is a need to examine input suppliers (seller sector) under this category and possible measures for switching the supplier sector from high- to low-polluting suppliers.

A single sector (Sector 3, i.e., padas stone and other minerals) is found under Category III. This possesses a high (over 50%) of TF_i^y/DiE but has a $TB_i^y/IDiE$ value of less than 50%, indicating that the sector emits considerable BOD to fulfill intermediate demand and that it does not cause other sectors to produce BOD for its input requirements. This category of sectoral pollution control will be better dealt with by implementing clean production technologies and wastewater treatment practices. No sectors can be found under Category IV, which is characterized by indirectly producing a huge amount of BOD from the other sectors and also directly producing a significant amount of BOD to supply other sector demand. Although we did

not find any sectors in this group, two sectors (i.e., Sectors 10 and 12) were extremely close to this category.

5. Policy implications and perspectives for pollution control

The analysis herein of sectoral water pollution behavior in the production process of the economy offers vital policy directives for controlling water pollution. In this study, livestock and poultry sectors were categorized as the chief BOD emitter; therefore, major attention should be paid to this sector. The handling and treatment of livestock waste is not common despite such waste containing valuable ingredients that can be processed for manure and biogas production. A typical BORDA biodigester can be used to handle animal waste in parts of Indonesia with satisfactory performance [18]. The optimization of biodigester performance and the expansion of its use comprise an effective method to control animal waste-derived water pollution. In relation to poultry waste, it is either composted or used for animal feedstuffs. Studies conducted globally and locally (i.e., in Indonesia) have demonstrated the possibility of turning poultry waste into valued feedstuffs for ruminants [47, 48]. Under the context of increased poultry waste, the policy of recovering animal waste and turning it into a valuable product would be the best option. Technical and financial issues in implementing related technologies should be supported by offering incentives. The application of the technologies (i.e., the biodigester or drying poultry manure for feedstuffs) would be more beneficial in terms of the technical and economic aspects for large-scale farming; therefore, policy encouraging the development of large-scale livestock and poultry farming should be prioritized. To minimize the pollutant loads from agriculture, fertilizer usage, including doses, timing, and methods, should be considered. Cleaner production and wastewater treatment practices should focus on the safe discharge of the wastewater

produced, especially from manufacturing industries such as Sectors 4 (food, beverage, coffee, and tobacco) and 8 (fuels and chemical industry, rubber, plastics).

Decreasing the total output of each sector by cutting its demand is the best method to control water pollution. The total output consists of the intermediate and final demands of the economy, while the final demand is further directed by exports, households, and gross stock. These components of demand should be carefully examined and considered in terms of pollution reduction. For instance, exports are responsible for producing a significant amount of BOD from major manufacturing industries such as Sectors 5 (textile, apparel, and leather goods), 6 (timber industry and wood products), 7 (paper industry, paper, and cardboard goods), 8 (fuels and chemical industry, rubber, plastics), and 9 (other processing industries). Curtailing the exports of these sectors based on their pollution loads to minimize the water pollution load could be an alternative. However, such policies should be examined from an economic and social perspective. Household consumption is the primary reason for BOD emissions by the top BOD emitters—Sectors 4 (food, beverage, coffee, and tobacco) and 2 (livestock and poultry). Changes in household consumption, including changes in dietary habits (e.g., shifting consumable food items toward environmentally friendly products), could be the best approach to minimize the PLs from these sectors. Although such changes may take time, starting initiatives in this area would significantly impact pollution control in the long term. Considering indirect roles, Sector 13 (hotels and restaurants) demonstrates significant impact on water pollution by indirectly inducing BOD. The indirect BOD discharge of Sector 13 is around 190 times higher than the sector's direct BOD emissions. This sends an important message—aside from focusing on pollution control practices within the premises of hotels and restaurants, policy should also seek and prioritize supply-side pollution (from associated sectors). This provides new insights, such as

offsetting the high investment cost for Sector 2 to adopt a wastewater treatment plant, by mobilizing the environmental fees/revenue collected from another sector, for example, the tourism sector. Alternatively, the possibility of decreasing the livestock and poultry population and increasing the imports of such products could be sought. Again, socioeconomic aspects should be evaluated for such decision-making

The classification of the sectors (Fig. 6) serves as a useful tool in planning appropriate pollution control policies. Managing demand by lowering household consumption, changing food habits (toward environmentally friendly food), and curtailing exports are effective methods to inhibit the water pollution of the sectors in Category I. Sectors under Category II are subject to pollution control by seeking alternative input suppliers (from high- to low-polluting suppliers) aside from the measures suggested for Category I. Sectors under Category III will be better managed by implementing clean production technology and wastewater treatment practices.

6. Conclusions

This study is the first to analyze the relationship between economic activity and the potential for water pollution in Bali, Indonesia. Going beyond conventional methods, potential water-polluting sectors were identified in this study based on their direct and indirect roles in BOD emissions. This study recognizes significant BOD emission drivers, guiding policymakers and practitioners to target initiatives that reduce Bali's water pollution. Certain sectors—namely, Sector 2 (livestock and poultry), Sector 1 (agriculture, forestry, and fishery), and Sector 4 (food and beverage)—accounted for 99.5% of the direct BOD discharge, among which Sector 2 accounted for 96% of the total BOD discharged. For direct BOD emissions, intermediate demand was a major driver in Sectors 1–3 and Sector 12. Similarly, exports were the cause of more than 60% of total BOD emissions for the manufacturing sectors (Sectors 5–9 and 13). Household

demand dominated the major portion of BOD emissions in Sectors 4 (food, beverage, coffee, and tobacco) and 10 (electricity, and drinking water).

In particular, we determined each sector's indirect BOD emissions. The livestock and poultry sector, the top BOD emitter, produced more than 50% of its BOD for its own sector demand, which was also recognized as the most self-polluting sector. Hotels and restaurants heavily rely on other sectors and were responsible for indirectly emitting BOD from different sectors. Sectors such as the trades, transportation, and service sectors, whose direct BOD emissions are limited, still significantly contributed to indirect BOD emissions.

Moreover, we grouped the sectors into four categories. Those in Category I emit considerable water pollutants for their own input requirements; these sectors are called self-polluters and are better addressed by demand management and employing clean production technologies. Sectors in Category II directly emit a significant portion of water pollutants for their own sector's input demand but heavily rely upon the total indirect water pollutants from other sectors. This category's pollution control will be better managed by shifting from high- to low-polluting suppliers in addition to the measures employed in Category I. Category III emits water pollutants to fulfill other (intermediate) sectoral demand; therefore, clean production technology and wastewater treatment should be encouraged. No sectors fell under Category IV, which produces and causes more water pollutants for and from other sectors, and for which a hybrid of the measures suggested for Categories II and III should be employed.

7. Limitations

For this research, we used an available 2007 I-O table; however, using the latest I-O data would have enhanced our analysis. The I-O table was extended by adding available BOD

emissions intensities. Establishing sub-sectoral pollution intensities and adding new water quality indicators could strengthen similar analyses in the future.

Declarations

Availability of data and materials

All data generated and analyzed during this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare they have no competing interests.

Funding

This work was carried out as part of the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS) project *Water for Sustainable Development (WSD)*, which is supported by the Ministry of Environment of Japan (MoEJ).

Authors' contributions

SKC contributed to the conceptualization, methodology, data interpretation, reviewing, and writing—original draft preparation. GM contributed to the methodology and data interpretation. ABR provided the data preparation and GIS map. CP processed the review and editing. IMS provided the policy implications. KF provided the supervision and funding acquisition. All authors read and approved the final manuscript.

Acknowledgments

The authors wish to thank the Ministry of Environment of Japan (MoEJ) for funding the project and Badan Pusat Statistik Provinsi Bali (Statistics of Bali Province) for providing the necessary data.

References

1. Boretti A, Rosa L. Reassessing the projections of the World Water Development Report. NPJ Clean Water. 2019;2:15. <https://doi.org/10.1038/s41545-019-0039-9>.
2. Kumar V, Parihar RD, Sharma A, Bakshi P, Singh Sidhu GP, Bali AS, et al. Global evaluation of heavy metal content in surface water bodies: A meta-analysis using heavy metal pollution indices and multivariate statistical analyses. Chemosphere. 2019;236:124364. <https://doi.org/10.1016/j.chemosphere.2019.124364>.
3. Flörke M, Kynast E, Bärlund I, Eisner S, Wimmer F, Alcamo J. Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study. Glob Environ Change. 2013;23:144–56. <https://doi.org/10.1016/j.gloenvcha.2012.10.018>.
4. Asian Development Bank. Asian Water Development Outlook 2013: Measuring water security in Asia and the Pacific. Mandaluyong City, Philippines; 2013. <https://www.adb.org/sites/default/files/publication/30190/asian-water-development-outlook-2013.pdf>. Accessed 13 February 2021.
5. Strauß S. Water conflicts among different user groups in South Bali, Indonesia. Hum Ecol. 2011; 39:69–79. <https://doi.org/10.1007/s10745-011-9381-3>.
6. BPS-Badan Pusat Statistik Provinsi Bali. Bali Province in Figures 2019, Denpasar, Bali; 2019.
7. Huntsman AC, White NG. Modernization in Bali, Indonesia and the influence of socio-economic factors on the nutritional status of preschool children in 1989/1990: An anthropometric study. Ann Hum Biol. 2007;34:411–24. <https://doi.org/10.1080/03014460701366373>

- 504 8. Siska ME, Sayama T, Takara K (2018a) Spatial and seasonal variabilities of water use and
505 availability in Bali. J JSCE, Ser B1 74:I_1333-I_1338.
506 https://doi.org/10.2208/jscejhe.74.I_1333
- 507 9. BPS-Badan Pusat Statistik Provinsi Bali. Strategic indicators. 2021
508 <https://bali.bps.go.id/QuickMap?id=0000000000>. Accessed 2 Feb 2021.
- 509 10. ARCOWA. Wastewater management and resource recovery in Indonesia: current status and
510 opportunities. 2018.
511 [http://seaknowledgebank.net/sites/default/files/wastewater_management_and_resource_reco](http://seaknowledgebank.net/sites/default/files/wastewater_management_and_resource_recovery_in_Indonesia_1.pdf)
512 [very_in Indonesia 1.pdf](http://seaknowledgebank.net/sites/default/files/wastewater_management_and_resource_recovery_in_Indonesia_1.pdf). Accessed 13 February 2021.
- 513 11. Rai IN, Shoba S, Shchegolkova N, Dzhamalov R, Venitsianov E, Santosa IGN, et al.
514 Analysis of the specifics of water resources management in regions with rapidly growing
515 population under different climate conditions: Case study of Bali Island and the Moscow
516 Region. Water Resour. 2015;42:735–46. <https://doi.org/10.1134/S0097807815050127>.
- 517 12. Cole S. A political ecology of water equity and tourism. Ann Tour Res. 2012;39:1221–41.
518 <https://doi.org/10.1016/j.annals.2012.01.003>.
- 519 13. Rimba AB, Mohan G, Chapagain SK, Arumansawang A, Payus C, Fukushi K, et al. Impact
520 of population growth and land use and land cover (LULC) changes on water quality in
521 tourism-dependent economies using a geographically weighted regression approach. Environ
522 Sci Pollut Res. 2021. <https://doi.org/10.1007/s11356-020-12285-8>.
- 523 14. Suteja Y, Dirgayusa IGNP, Purwiyanto AIS. Chromium in Benoa Bay, Bali - Indonesia. Mar
524 Pollut Bull. 2020;153:111017. <https://doi.org/10.1016/j.marpolbul.2020.111017>
- 525 15. Wayan Budiasa I, Gusti Ngurah Santosa I, Nyoman Sunarta I, Ketut Suada I, Nyoman Rai I,
526 Ratna Dewi AAI, et al. The Potential Use of Bali Wastewater for Crop Production Based on

527 Moscow Region Experience. Water Resour. 2018;45:138–147.
 528 <https://doi.org/10.1134/S0097807818010074>.

529 16. Suteja Y, Purwiyanto AIS. Nitrate and phosphate from rivers as mitigation of eutrophication
 530 in Benoa bay, Bali-Indonesia. IOP Conf Ser: Earth Environ Sci. 2018;162:012021.
 531 <https://doi.org/10.1088/1755-1315/162/1/012021>.

532 17. Lewis J, Lewis B. Bali's silent crisis: desire, tragedy, and transition. Lexington Books; 2008.

533 18. WEPA-Water Environment Partnership in Asia. Water standards of partner countries. 2017.
 534 <http://wepa-db.net/en/topic/waterstandard/index.html>. Accessed 2 Mar 2021.

535 19. Rochmadi R, Ciptaraharja I, Setiadi T. Evaluation of the decentralized wastewater treatment
 536 plants in four provinces in Indonesia. Water Pract Technol. 2010;5:4: wpt2010091.
 537 <https://doi.org/10.2166/wpt.2010.091>.

538 20. Pramono, J. The process of environmental management at star rated hotel in Bali. Tourism &
 539 sustainable regional development In Indonesia. 2016;20-32.

540 21. Nguyen HT, Aviso KB, Kojima N, Tokai A. Structural analysis of the interrelationship
 541 between economic activities and water pollution in Vietnam in the period of 2000–2011.
 542 Clean Techn Environ Policy. 2018;20:621–38. <https://doi.org/10.1007/s10098-018-1492-8>.

543 22. Hoang LE A, Tokai A, Yamamoto Y (2012) Structural analysis of relationship between
 544 economic activities and water pollution in Vietnam. J. Japan Soc. Hydrol. and Water Resour.
 545 2012;25:139–151. <https://doi.org/10.3178/jjshwr.25.139>.

546 23. Ang JB. Economic development, pollutant emissions and energy consumption in Malaysia. J
 547 Policy Model. 2018;30:271–278. <https://doi.org/10.1016/j.jpolmod.2007.04.010>.

548 24. Duarte R, Yang H. Input–output and water: introduction to the special issue. Econ Syst Res.
 549 2011;23:341–51. <https://doi.org/10.1080/09535314.2011.638277>.

- 550 25. Ali SH, Puppim de Oliveira JA. Pollution and economic development: an empirical research
551 review. *Environ Res Lett.* 2018;13:123003. <https://doi.org/10.1088/1748-9326/aace7>.
- 552 26. Chapagain SK, Mohan G, Fukushi K. An extended input–output model to analyze links
553 between manufacturing and water pollution in Nepal. *Water Air Soil Pollut.* 2020;231:570.
554 <https://doi.org/10.1007/s11270-020-04940-0>.
- 555 27. Resosudarmo BP. River water pollution in Indonesia: an input-output analysis. *IJESD*
556 2003;2:62. <https://doi.org/10.1504/IJESD.2003.002363>.
- 557 28. Sánchez-Chóliz J, Duarte R. Water pollution in the Spanish economy: analysis of sensitivity
558 to production and environmental constraints. *Ecol Econ.* 2005; 53:325–338.
559 <https://doi.org/10.1016/j.ecolecon.2004.09.013>.
- 560 29. JICA- Japan International Cooperation Agency. The comprehensive study on water resources
561 development and management in Bali Province in the Republic of Indonesia final report.
562 2006.
- 563 30. Sanchez-Choliz J, Duarte R. Analysing pollution by way of vertically integrated coefficients,
564 with an application to the water sector in Aragon. *Cam J Econ.* 2003; 27:433–448.
565 <https://doi.org/10.1093/cje/27.3.433>.
- 566 31. Tanaka FJM. Applications of Leontief's input-output analysis in our economy. *Faculty of*
567 *Economics Journal University of Nagasaki.* 2011;45:1, 29–96.
- 568 32. Miller RE, Blair PD. *Input–output analysis: Foundations and extensions (2nd ed).*
569 *Cambridge: Cambridge University Press; 2009.*
- 570 33. Mohan G, Chapagain SK, Fukushi K, Papong S, Sudarma I. M, Rimba AB, et al. An
571 Extended Input–Output Framework for Evaluating Industrial Sectors and Provincial-Level

572 Water Consumption in Indonesia. *Water Resour Ind.* 2021;100:141.
 573 <https://doi.org/10.1016/j.wri.2021.100141>.

574 34. Kitzes J. An Introduction to environmentally-extended input-output analysis. *Resources*.
 575 2013;2:489–503. <https://doi.org/10.3390/resources2040489>.

576 35. Donati F, Aguilar-Hernandez GA, Sigüenza-Sánchez CP, de Koning A, Rodrigues JFD,
 577 Tukker A. Modeling the circular economy in environmentally extended input-output tables:
 578 Methods, software and case study. *Resour Conserv Recycl.* 2020;152:104508.
 579 <https://doi.org/10.1016/j.resconrec.2019.104508>.

580 36. Chakraborty D, Mukhopadhyay K. *Water Pollution and Abatement Policy in India*. vol. 10.
 581 Dordrecht: Springer Netherlands; 2014. <https://doi.org/10.1007/978-94-017-8929-5>.

582 37. Damania R, Desbureaux S, Rodella A-S, Russ J, Zaveri E. *Quality Unknown: The Invisible*
 583 *Water Crisis*. Washington, DC: World Bank; 2019. [https://doi.org/10.1596/978-1-4648-1459-](https://doi.org/10.1596/978-1-4648-1459-4)
 584 [4](https://doi.org/10.1596/978-1-4648-1459-4).

585 38. Wen Y, Schoups G, van de Giesen N. Organic pollution of rivers: Combined threats of
 586 urbanization, livestock farming and global climate change. *Sci Rep.* 2017; 7:43289.
 587 <https://doi.org/10.1038/srep43289>.

588 39. JICA- Japan International Cooperation Agency. *The development study on wastewater*
 589 *disposal for Denpasar*. 1993.

590 40. Jha S, Mani M. *Trade liberalization and the environment in Vietnam*. Washington, D.C.: The
 591 World Bank; 2006. <https://doi.org/10.1596/1813-9450-3879>.

592 41. BPS-Badan Pusat Statistik Provinsi Bali. *Bali Province in Figures 2008*, Denpasar, Bali;
 593 2008.

42. Boyd CE. Effluent effects from aquaculture pond. In Global Aquaculture Alliance. 2006.
<https://www.aquaculturealliance.org/advocate/effluent-effects-from-aquaculture-ponds/>.
Accessed 30 Aug 2020.
43. Choi D-H, Beom J-A, Jeung M-H, Choi W-J, Her Y-G, Yoon K-S. Characteristics of biochemical oxygen demand and chemical oxygen demand export from paddy fields during rainfall and non-rainfall periods. Paddy Water Environ. 2019;17:165–75.
<https://doi.org/10.1007/s10333-019-00708-3>.
44. Vigiak O, Grizzetti B, Udias-Moinelo A, Zanni M, Dorati C, Bouraoui F, et al. Predicting biochemical oxygen demand in European freshwater bodies. Sci Total Environ. 2019;666:1089-1105. <https://doi.org/10.1016/j.scitotenv.2019.02.252>.
45. Verheijen LAHM, Wiersema D, Pol LH, De Wit J. Management of waste from animal product processing. International Agriculture Center, Wageningen, The Netherlands; 1996.
46. Gu P, Shen RF, Chen YD. Diffusion pollution from livestock and poultry rearing in the Yangtze Delta, China. Environ Sci Pollut Res. 2018;15:273–277.
<https://doi.org/10.1065/espr2007.07.438>.
47. Adli DN, Sjöfjan O, Mashudi M. Dried of Poultry Waste Urea-Molasses Block (dpw-umb) as Potential for Feed Supplementation. J Agripet. 2017;17:144–149.
<https://doi.org/10.17969/agripet.v17i2.8391>.
48. Ghaly AE, MacDonald KN. Drying of poultry manure for use as animal feed. Am J Agric Biol Sci. 2012;7:239–254. <https://doi.org/10.3844/ajabssp.2012.239.254>.

617 **List of Figures**

Fig. 1 Map depicting the location of Bali Province

618

Fig. 2 Sectoral distribution of the gross regional domestic product (GRDP) of Bali, 2018

619

Fig. 3 Sectoral direct discharge of BOD in the Balinese economy, 2007 (in tons)

620

Fig. 4 Percentage of total BOD discharge attributable to each component of each sector's total output
Note: Sectors 11, 14, and 15 do not release significant BOD

621

Fig. 5 Indirect BOD discharged by each sector relative to total BOD discharge in the Balinese economy, 2007

Fig. 6 Classification of sectors based on their BOD emissions characteristics

622 **List of Tables**

623 **Table 1** Schematic representation of a conventional I–O table.

624

Sector	Intermediate sector					Final demand	Total output
<div><div>(Buyer) j</div><div>(Seller) i</div></div>	1	...	j	...	n		
1	x_{11}	...	x_{1j}	...	x_{1n}	d_1	x_1
.	.	...		...			
.	.	...		...			
i	x_{i1}	...	x_{ij}	...	x_{in}	d_i	x_i
.	.	...		...			
.	.	...		...			
n	x_{n1}	...	x_{nj}	...	x_{nn}	d_n	x_n
Value added	v_1	...	V_j	...	v_n		
Imports	m_1	...	m_j	...	m_n		
Total inputs	x_1	...	x_j	...	x_n		

625

	Sector ID	Intermediate Demand																Final Demand			Total Output
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	HH	G&S	Ex	
	Economic sector (Million IDR)																				
	1	490,069	70,629	-	1,605,659	62,833	1,076	-	271,399	384	-	812	75	1,297,237	-	-	2,315	3,296,677	236,418	1,405,813	8,741,397
	2	12,230	2,551,914	-	25,849	-	-	-	-	252	-	-	-	1,403,216	-	-	78	2,696,820	101,999	170,948	6,963,305
	3	-	-	-	-	-	-	-	-	-	-	367,007	-	-	-	-	46	-	227	50,021	417,300
	4	14,136	268,643	-	75,661	781	-	-	1,151	230	3	-	-	534,105	858	-	525	1,450,355	-248,937	785,353	2,882,865
	5	12,569	19	38	54	493,567	2,103	-	2,031	841	-	-	905	129,768	37,778	1,297	55,724	542,996	-48,641	3,342,331	4,573,381
	6	1,973	1,370	4,169	4,260	230	151,887	-	-	2,760	-	200,430	30,909	92,550	6,688	55	2,060	20,324	5,531	1,534,663	2,059,858
	7	1,071	83	38	115	981	1,110	2,713	2,288	719	160	579	1,177	5,767	1,225	2,545	2,940	41,113	67	88,951	153,640
	8	103,684	12,878	1,825	955	79,155	18,902	3,964	96,983	1,896	429	21,923	58,726	15,157	1,628	237	56,688	51,849	458	778,493	1,305,829
	9	5,553	101	29	263	7,116	5,137	45	2,528	978	113	6,397	16,164	5,816	3,897	548	5,310	4,906	3,511	147,572	215,984
	10	1,077	15,262	295	2,104	116,302	11,182	7,938	6,422	5,776	10,451	6,834	17,432	288,250	17,679	33,791	39,622	647,805	-	-	1,228,222
	11	64,298	8,140	46,643	1,424	1,260	4,144	3	3,009	71	2,623	248,726	149,945	105,117	119,524	80,480	180,056	-	4,433,706	-	5,449,172
	12	199,339	688,772	2,466	196,903	215,098	69,286	3,270	86,122	4,191	353	288,476	59,660	1,030,813	22,410	2,036	51,660	2,374,230	12,830	1,603,081	6,910,996
	13	46,852	4,042	230	13,444	70,675	2,987	-	-	1,416	6,173	11,557	94,023	215,976	393,577	18,164	212,151	1,720,026	-	12,639,812	15,451,107
	14	62,144	207,974	2,199	56,271	102,861	21,459	947	24,655	2,477	8,143	92,380	30,960	322,761	531,300	24,062	67,650	1,214,247	3,627	4,708,397	7,484,513
	15	764	1,103	5,718	1,142	48,776	9,899	262	5,838	292	653	14	95,058	64,985	25,062	35,799	52,683	254,666	-	832,194	1,434,908
	16	306,510	73,514	2,865	22,560	165,616	54,270	9,652	71,326	6,768	26,688	178,052	802,718	450,100	286,000	24,783	464,159	2,563,134	4,276,203	2,699,610	12,484,528
	BOD (kg/million IDR)	0.812	34,010	0.276	0.657	0.014	0.015	0.105	0.277	0.040	0.000	0.000	0.000	0.025	0.000	0.000	0.005				

Sector	Description		
1	Agriculture, forestry, & fishery	11	Construction
2	Livestock & poultry	12	Trading
3	Padas stone & other minerals	13	Hotels & restaurants
4	Food, beverage, tobacco, & coffee industries	14	Transportation, travel bureau, & other transportation support services
5	Textile, apparel, & leather goods industries	15	Communications, post, & giro
6	Timber industry, & wood products	16	Financial institutions & company services
7	Paper industry, paper, & cardboard goods	HH	Household consumption
8	Fuels, chemical industry, rubber, & plastics	G&C	Gross fixed capital and stock change
9	Other processing industries	Ex	Export
10	Electricity & drinking water		

629 **Table 3** Matrix of BOD (kg) flow in the economy.
630

Sector ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	4,271,454.1	135,375.3	61.8	985,474.1	74,304.2	4,529.4	711.7	162,216.4	758.7	433.0	7,873.6	13,838.6	1,379,795.0	34,546.0	1,724.7	28,449.6
2	581,348.1	159,642,177.2	488.3	1,189,520.3	409,447.6	28,480.4	1,613.9	37,589.1	16,625.5	19,070.0	114,257.0	331,609.2	71,781,314.7	1,709,937.8	80,402.5	879,231.9
3	906.6	443.8	13,977.0	322.7	303.3	128.0	5.5	130.6	6.0	34.8	87,253.2	1,954.3	3,278.4	2,195.3	1,248.9	2,961.6
4	7,103.0	122,915.8	3.0	1,343,289.3	2,892.9	177.3	12.2	892.3	159.2	108.1	671.1	1,890.6	398,284.1	9,996.8	449.6	5,197.1
5	143.5	30.1	0.2	42.3	59,692.5	34.1	0.9	33.6	10.4	2.0	30.1	57.2	2,043.5	569.0	21.5	721.8
6	66.0	76.9	12.1	82.2	42.6	25,837.8	0.5	11.4	33.8	1.7	2,935.6	375.2	1,696.2	209.2	45.1	151.2
7	95.8	31.1	0.8	37.5	145.2	107.4	13,926.4	177.1	56.8	10.0	90.0	115.3	711.1	145.8	215.3	285.1
8	19,396.1	4,691.0	78.7	5,147.1	23,482.0	4,904.0	1,044.7	248,654.7	446.1	98.8	7,601.1	11,267.7	17,246.0	1,655.9	245.3	14,371.1
9	161.8	63.2	0.6	61.5	309.5	178.9	2.4	84.1	6,292.4	3.1	276.0	403.9	450.6	161.8	22.9	199.2
10	0.7	2.5	0.0	0.6	21.7	1.9	1.3	1.0	0.8	122.8	1.9	2.9	55.5	4.7	5.1	7.3
11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	12.7	46.1	0.1	16.6	20.8	5.6	0.3	6.2	0.3	0.1	24.8	379.8	122.7	5.7	0.7	6.8
13	927.9	559.9	2.5	585.3	2,050.9	141.7	7.9	111.7	34.0	97.1	577.2	1,682.9	365,978.0	8,713.8	409.6	4,457.4
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	1,164.8	684.4	3.9	469.1	1,116.0	302.5	50.9	364.7	32.3	81.9	1,102.5	2,678.6	3,937.2	1,507.0	137.2	53,217.2

Sector	Description		
1	Agriculture, forestry, & fishery	9	Other processing industries
2	Livestock & poultry	10	Electricity & drinking water
3	Padas stone & other minerals	11	Construction
4	Food, beverage, tobacco, & coffee industries	12	Trading
5	Textile, apparel, & leather goods industries	13	Hotels & restaurants
6	Timber industry & wood products	14	Transportation, travel bureau & other transportation support services
7	Paper industry, paper, & cardboard goods	15	Communications, post, & giro
8	Fuels, chemical industry, rubber, & plastics	16	Financial institutions & company services

631

632 **Table 4** Disaggregated sectoral pollution components with BOD loads (in tons).

Sector	Own pollution (OW_i^y)	Semi-own pollution (SOW_i^k)	True forward pollution (TF_i^y)	True backward pollution (TB_i^y)	Final demand pollution (FD_i^y)
1. Agriculture, forestry, & fishery	240	22.5	2,830	611	4,012
2. Livestock & poultry	58,506	134.2	77,181	265	101,002
3. Padas stone & other minerals		0.1	101	1	14
4. Food, beverage, tobacco, & coffee industries	35	2.7	551	2,182	1,305
5. Textile, apparel, & leather goods industries	6	0.0	4	514	53
6. Timber industry & wood products	2	0.0	6	39	24
7. Paper industry, paper, & cardboard goods	0	0.0	2	3	14
8. Fuels, chemical industry, rubber, & plastics	18	-0.2	112	202	230
9. Other processing industries	0	0.0	2	18	6
10. Electricity & drinking water	0	0.0	0	20	0
11. Construction	-	0.0	-	223	-
12. Trading	0	0.0	0	366	0
13. Hotels & restaurants	0	7.0	20	73,589	359
14. Transportation, travel bureau, & other transportation support services	-	0.0	-	1,770	-
15. Communications, post, & giro	-	0.0	-	85	-
16. Financial institutions & company services	0	2.1	14	936	51

633

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryA.docx](#)