Recognising the Value of Water for Sustainable Development

United Nations University
Institute for the Advanced Study of Sustainability

THE GLOBAL GOALS
For Sustainable Development

Contents

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Background

The Water Environment in Asia

Water is a precious natural resource essential for the sustainable development of societies, the economy, and the environment. Although water is abundant in nature, only about 3% of water resources exist in freshwater to satisfy human and societal needs (Cassardo & Jones, 2011). Moreover, the resource varies across the globe on both spatial and temporal scales, and thereby, the availability of water greatly differs among and within regions.

Of the total freshwater resources, about 36% belong to Asia Pacific supporting the lives and livelihood of 60% of the world's population. As such, the region has the lowest per capita water availability in the world (UN, 2014). The region has a wide range of climates and possesses a variety of hydrological regimes with a distinct inter-seasonal variation. Agriculture is the dominant water user, accounting for about 79.2% of the region's total water withdrawal in 2002. The industrial and domestic water uses were 13.1% and 7.7% of the total water withdrawal, respectively (UNESCAP, 2008). The region is vulnerable to serious water stress in the coming decades, as population and economic growth drive further production and consumption of foods and products.

Major Challenges

Freshwater resources are experiencing immense pressure due to increasing water demand and water pollution levels in Asia. Global climate change also threatens water resources and livelihoods (Alexander & West, 2011). Many countries of the Asia-Pacific region have encountered difficulties in sustaining the available water resources, and the situation is likely to continue, leading to long-term water scarcity. Notably, the per capita water withdrawal has already risen in Asia, and the negative consequences of over-drafting have become visible.

Key water challenges in Asia can be summarised as follows.

Higher Demand for Water: Asia has experienced the most dynamic economic growth favoured by increased trade through globalisation in the last half a century. Reflecting the rapid economic upturn, population growth and urbanised lifestyles, changes in food demand and consumption patterns have accelerated water use. The increased food demand stimulated an enormous rise in water use, while the agriculture sector consumes as much as 79.2% of the 2,393.4 billion m^3 total regional withdraw in 2002, which is far above the global average withdrawal (UNESCAP, 2008). Additionally, the withdrawal for industrial and domestic water uses has also escalated. The surge in water demand has catalysed the unsustainable withdrawal of the resources, which has ultimately put the region's sustainable growth into doubt.

Water Quality Degradation: With a large population and a rapidly growing economy, waste and wastewater production have increased enormously in the region. An increased level of pollution was reported in 50% of major rivers in Asia in 1990–2010 (ADB, 2020). The existing production practices and waste and wastewater handling are not environmentally sustainable: almost 80% of untreated wastewater is directly discharged into waterways (ADB, 2020). Despite the water quantity remaining unchanged, the increased level of water pollution has intensified water scarcity by shrinking usable freshwater resources.

Climate Variability: The region has a wide range of climates. The monsoon is a typical climate characterised by the incidence of major precipitation within a short period, causing high inter-seasonal flows, where *too much* and *too little* water conditions have gradually become the norm. Flooding is a common problem in the Mekong, Brahmaputra and Ganges basins; drought and water scarcity are common in Central China (Alexander & West, 2011). The huge seasonal and geographical disparities in climate and precipitation in Asia Pacific make water management more challenging (UNDP, 2022).

Global climate change impacts the rainfall pattern, causing more frequent floods and droughts. It has directly impacted the water resources leading to high river discharge and diminishing groundwater infiltration and subsequent storage. Moreover, the frequent incidence of water disasters (such as floods) has caused increased threats to reliable water supplies by damaging the water storage and supply systems (UNICEF, 2022).

Institutional and Policy Gap: The governments of the region have tried to integrate environmental concerns into their national development plans. Nonetheless, the water environment is yet to see improvements, due to the lack of integrated management plans for water resources. Even the existing plans have not been implemented due to limited research and technical capacity (such as the collection and monitoring of data, poor knowledge on available resources and water demand, the lack of physical infrastructure), the weak governance system (including effective policies and regulations and inter-agency coordination), and insufficient awareness (including on the need to integrate environmental concerns into economic development planning).

Progress toward Attaining Water-Related Sustainable Development Goals

Countries of the Asia-Pacific region are committed to achieving the UN Sustainable Development Goals (SDGs); however, with the current pace of progress, the region may achieve no more than 10% of the SDG targets (UNESCAP, 2021). In relation to SDG6 on water and sanitation, overall progress is slow in the region except for specific targets, such as reducing open defecation. About 300 million people still lack access to safely managed or basic services of drinking water, and 1.2 billion lack adequate sanitation (ADB, 2020).

The region needs to build greater capacity for participatory water and sanitation management and water-use efficiency to achieve the 2030 targets (UNESCAP, 2021). ADB (2020) highlighted that out of the 49 ADB members from Asia and the Pacific, 27 face severe water constraints on economic development. Owing to the centripetal role of water (SDG6) to achieve the other SDGs targets, it is imperative to seek an appropriate water management policy.

Objectives and Methodology

Objectives

This casebook presents the outcomes of the Water for Sustainable Development (WSD) research project implemented by the United Nations University Institute for the Advanced Study of Sustainability (UNU-IAS), a leading research and teaching institute dedicated to realising a sustainable future through evidence-based knowledge and solutions for policymaking and priority issues for the UN system. The publication is aimed at policymakers, water practitioners, researchers, and students interested in learning and utilising the analytical framework developed by WSD. As an integral part of UNU-IAS work on water and resource management, WSD was implemented from April 2018 to March 2022 with the following objectives:

1) Develop an analytical framework to evaluate the role and value of water for sustainable development in selected locations in Asia.
2) Utilising the framework developed in (1), produce future scenarios tailored for each location, demonstrating water consumption and water pollution at different levels of economic growth.
3) Propose policy options that guide environmental sustainability of production activities in each location.

The outcomes of this research will accelerate the efforts toward achieving the Sustainable Development Goals (SDGs), with a focus on Goals 6.3 (improvement of water quality) and 6.4 (increase in water efficiency).

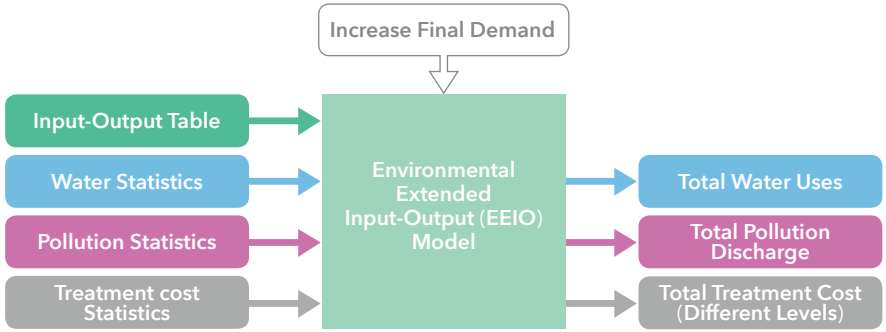
Methodology

The methodology employed for the research is called Input-Output (IO) analysis. IO analysis is concerned with "the activity of a group of industrial sectors that both produce goods (outputs) and consume goods from other industrial sectors (inputs) in the process of producing each industry's own output" (Miller & Blair, 2012). This research utilises a traditional Leontief IO model, an extensively used and valuable method to construct an IO table by observing economic data for a selected geographical location for a specific time period.

Environmentally-Extended Input-Output (EEIO) Model

A regional IO table is developed for a selected case study location from a national IO and is extended to include environmental components by adding additional rows with physical data on water use, with water pollutant loads in each sector considered as a production factor. The result of the analysis provides a comprehensive matrix of intersectoral dependence, in terms of economy, water consumption and pollution loads.

The EEIO method enables the analysis of the dual roles of a sector as an input supplier and an input receiver in the production process of an economy. Based on these roles, water pollution is distinguished into two categories: direct (as a source) and indirect (as a cause). For instance: direct pollution is the amount of pollutant load that is directly discharged by a sector in the production of total outputs that satisfy all forms of demands in the economy. By contrast, indirect pollution of a sector is the amount of water pollutants that a sector is responsible for discharging within a sector and other sectors in in fulfilling the inputs demanded. In this way, the application of the IO model to water resources can visualise the intersectoral demand-supply relationships and help identify key economic sectors that drive water consumption and pollution, whether explicitly or implicitly.



Flow Chart of EEIO Model.

Selection Criteria for Case Study Locations

The criteria were chosen based mainly on the region's dominant economic sectors (e.g., agriculture, services and industry-based). In the case of the province of Bali in Indonesia, accommodation and food services are the dominant sectors; in Kaski district in Nepal, agriculture and forestry sectors. For the other two case studies, Visakhapatnam district in India and Rayong province in Thailand, manufacturing sectors are dominant.

In addition, the selected locations have high pressures on water resources (water access and water quality) due to increasing economic activities and development. The most of the secondary data related to the economy, water use, and water quality were obtained from project partners in respective case study locations, the collaboration with whom constituted another vital criterion for choosing the study locations.

Data Sources

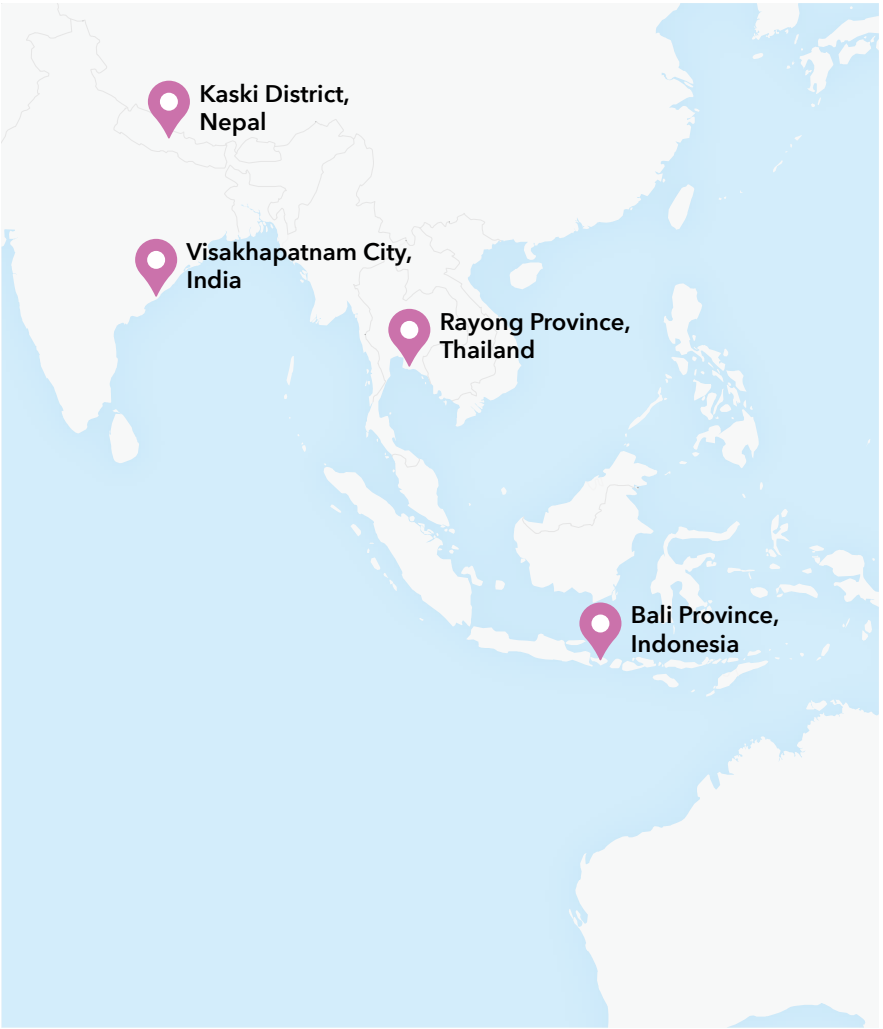
In order to construct the EEIO, two datasets are required: (i) a regional IO table that facilitates investigating the flows of goods and services among producers and consumers, and the interrelationships between all economic sectors, (ii) environmental data, including sectoral water use coefficients (the quantity of freshwater consumption to produce an output unit of sales or purchases in all economic sectors), and water pollutant discharge coefficients (unit water pollution loads with sectoral total outputs).

1) *Regional IO Economic Table*
   This project developed an EEIO for Bali province in Indonesia, Kaski district in Nepal, Visakhapatnam city in India, and Rayong province in Thailand, based on the regional, provincial and district IO tables (in monetary value units). Except for Bali province, IO tables were created for each location by downscaling the IO tables from national to district and province level, using the Cross-industry Location Coefficient (CILC) method (Flegg et al., 1995). The IO table structure includes the flow of intermediate consumption of production sectors, final consumption and exports, and the use of imports.

2) *Environmental Data (Water Use and Water Pollution)*
   Disaggregated data on water consumption and on the discharge of pollutants was not available in any of the case study sites. Therefore, these datasets were compiled and analysed by using different government data sources, published reports and peer-reviewed articles. For example, the water data for Bali province was taken from the water consumption inventory database (Ono et al., 2017). In the case of Kaski district, water use data was taken from FAO AQUASTAT (2011) for the agricultural sector. Data for the manufacturing sector was determined based on water use coefficients per employee as provided by Malla et al. (2019), and hotels and restaurants data was determined on the basis of 100 litres per bed as provided by the national building code. For Visakhapatnam city in India and Rayong province in Thailand, the sector-wise water use data was taken from Bogra et al. (2016) and Chuenchum et al. (2018).

Related to water quality, the biochemical oxygen demand (BOD) was taken as a widely used proxy water quality parameter, and the amount of BOD discharge from economic activities was also estimated from various sources in the absence of available data. In Bali, the sectoral BOD discharge from manufacturing was derived from a report on wastewater disposal for Denpasar (JICA, 1993). The BOD coefficients from agriculture and livestock sectors were estimated indirectly taking into account the amount of agricultural land and livestock (cattle and poultry) heads together with unit BOD discharge from agricultural land and livestock. For hotels and restaurants, the total number of visitors and restaurant seats were used together with BOD load per capita (visitor) per day and per restaurant seat. The details of BOD calculations are provided in Chapagain et al. (2022). A similar approach was employed in Nepal, while manufacturing sectoral coefficients were obtained from Chapagain et al. (2020). In the Visakhapatnam case study, sector-wise BOD coefficients were taken from Chakraborty and Mukhopadhyay (2014). In the case of Rayong province, manufacturing sectoral BOD pollution was estimated by using the coefficient (UNIDO, n.d.) and manufacturing census data. Agriculture and hotel restaurants were also estimated in the same way in Bali, Indonesia.

Case Study Locations



Bali Province, Indonesia

Geographical area: 5,620 km²
Population: 4,380,800 (as of 2020)
Climate zone: tropical marine
Annual rainfall: 1,741 mm/year
Temperature range: 22.7–32.9°C (2018)

Dominant economic sectors
(2018, GPDP share, %)
Accommodation and Food service activities: *23.4*
Agriculture, forestry and fishing: *13.8*
Transportation and storage: *9.7*

Type of water resources
Rivers, groundwater and springs

Kaski District, Nepal

Geographical area: 2,017 km²
Population: 599,504 (as of 2021 Census)
Climate Zone: sub-tropical
Annual rainfall: 3,105 mm/year (average)
Temperature range:
0.5–35 °C (average); 6.6–35 °C (2016)

Dominant economic sectors
(2011, GDDP share, %)
Agriculture and forestry: *22.6*
Real estate, renting and Business activities: *13.5*
Education: *12.2*

Type of water resources
Rivers, groundwater and lakes

Visakhapatnam City, India

Geographical area: 11,161 km²
Population: 4,574,261 (as of 2022)
Climate: tropical wet and dry climate
Annual rainfall: 1,273 mm/year (2020)
Temperature range: 21.5–34.2 °C (2020)

Dominant economic sectors
(2019, GDDP share, %)
Manufacturing: *26.1*
Trade, hotel & restaurants: *19.9*
Transport by other means & storage: *8.3*

Type of water resources
Rivers and groundwater

Rayong Province, Thailand

Geographical area: 3,552 km²
Population: 723,316 (as of 2018)
Climate: tropical
Annual rainfall: 1,598 mm/year (2020)
Temperature range: 17.9–35.3 °C (2020)

Dominant economic sectors
(2015, GPDP share, %)
Manufacturing: *44.1*
Mining and quarrying: *33.5*
Wholesale and retail trade, and repair of motor vehicles and motorcycles: *7.1*

Type of water resources
Rivers and groundwater

GDDP: Gross District Domestic Product
GPDP: Gross Provincial Domestic Product

Water Use

This section describes the total water use by sector, consumed both directly and indirectly from economic activities in the case studies sites. It illustrates how water consumption of one sector is influenced by the trade relationships within the economy.

Bali Province, Indonesia

With the significant growth of the population and tourism infrastructure, water supply is considered critical. Over the past 10 years, the water tables across Bali have dropped up to 50m; 60% of its watershed has been declared dry (Wright, 2016). In 2011, the primary freshwater resources in Bali province were groundwater (46,606 million m^3; 30.9%), followed by springs (38,314 million m^3; 25.4%), rivers (48, 881 million m^3; 32.4%) and others (6,182 million m^3; 4.1%). According to the Ministry of Public Works (2015), 41.0% of the rivers in Bali are perennial, while others could dry up depending on the season – indicating the difficulties of securing stable water supply in the province. In addition, the consumption of groundwater in Bali province is increasing year by year. The groundwater consumption in 2015 increased by 20,807 million m^3 or by 9.2%, likely due to the continued demand by the tourism sector for the maintenance of swimming pools and gardens, among others. Innovative solutions are necessary to sustainably manage available water resources.

As in many developing countries, the agricultural sector consumes the largest amount of water in Bali: rice (0.7 billion m^3), maize (0.1 billion m^3), plantation/non-food crops (0.8 billion m^3) and livestock (0.01 billion m^3) (Mohan et al., 2021).

Total water consumption can demonstrate the composition of their direct and indirect water consumption. The direct water consumption is high in agricultural sectors: 83% of water used for rice production is brought directly from surface water sources (e.g., rivers and springs) or from groundwater sources. The percentage of direct water consumption is 85% for maize, 67% for plantation/non-food crops, 90% for other food crops and 76% for livestock (Mohan et al., 2021).

The manufacturing and service sectors have a significantly higher indirect water consumption (Figure 2). This implies that they use only a small amount of water in their own production activities but are driving water demand in other sectors – resulting in high water consumption in the value chain. Indirect water consumption is significantly higher in sectors such as timber industry and wood products; car body industry and transportation equipment; and construction. To maximise water efficiency in Bali's economic activities, more attention should be given to saving water indirectly consumed in the production process.

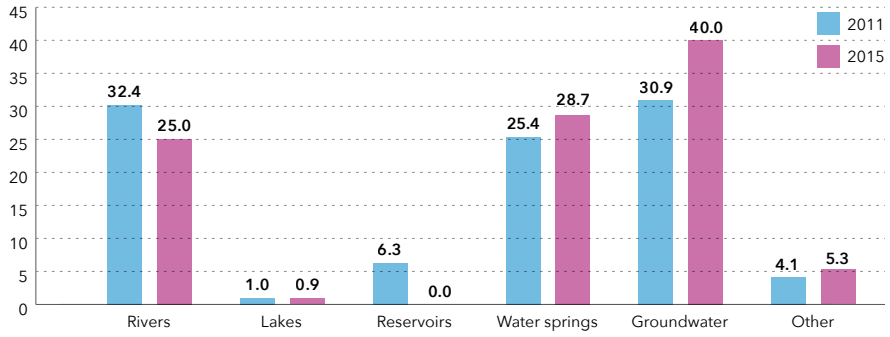


Figure 1: Freshwater resources in Bali, Indonesia, 2011 and 2015 (percent)

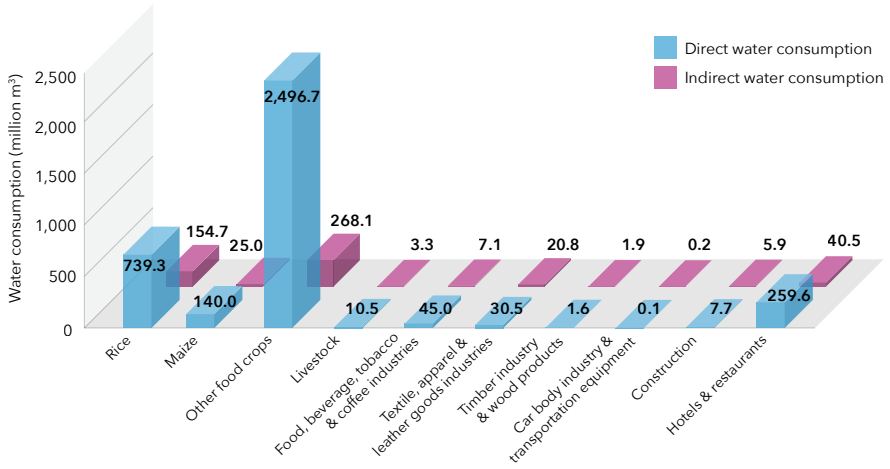


Figure 2: Sector-wise direct and indirect water consumption in Bali, Indonesia

Kaski District, Nepal

Kaski district in Nepal is located in the Western Development Region. The district covers 2,017 km^2 and is rich in water resources represented by rivers such as Seti Gandaki, Modi and Madi, besides other streams. Despite its enormous water resources, its residents have only limited access to sufficient water to meet their domestic, agricultural and industrial needs due to extreme topography, increasing rapid urbanisation and population growth. In addition, to meet the increasing demand for water, the current water resources are being diverted from agriculture and rural domestic use to non-agricultural activities, including urban, residential, industrial and tourism service.

According to the EEIO analysis conducted for Kaski district (Figure 3), the total direct water consumption for 15 sectors amounted to 139 million m^3 of water, out of which agriculture, forestry and fishing sector consumes 83.1% or 115 million m^3 followed by the electricity, gas and water sector (22 million m^3, 16.0%), hotels and restaurants (0.20 million m^3, 0.14%), food products (0.10 million m^3, 0.07%) and beverages (0.07 million m^3, 0.05%). Indirect water use, however, is attributed primarily to the manufacturing sectors such as the textiles sector (0.009 million m^3) and rubber and plastic products (0.001 million m^3).

Harsh competition over water among different economic actors implies that industries could experience water insecurity not because of physical scarcity of water but because of the competition. An integrated approach, and the application of water budgeting method, could assist water governance in overcoming challenges and achieve sustainable management of water resources.

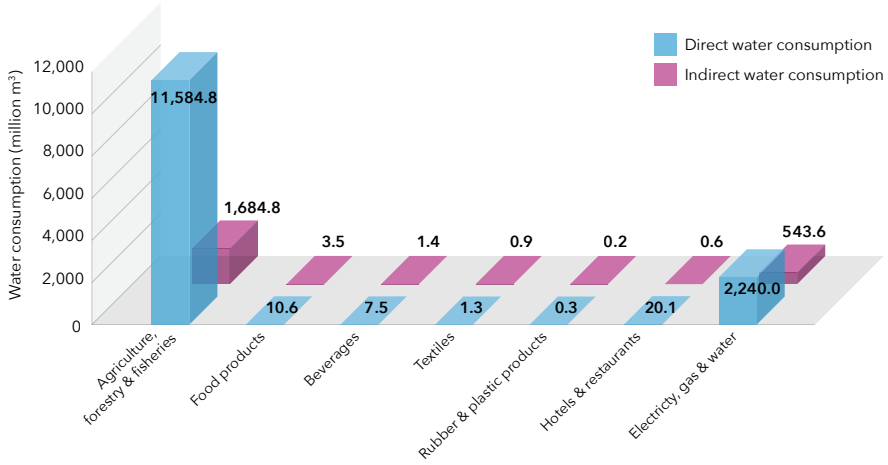


Figure 3: Sector-wise direct and indirect water consumption in Kaski, Nepal

Visakhapatnam City, India

Visakhapatnam is the second-largest city and one of the smart cities in the state of Andhra Pradesh, India, having extensive industrial growth and rapidly increasing population in urban areas (DHBS, 2020). Growing economic and urban expansion has led to higher pressure on water resources; as a result, there are changes in the spatial land use and land cover patterns from 2006-2016 that clearly show the decrease of productive agricultural lands (0.23%), loss of forest cover (-2.25%), loss in surface water bodies (-0.89%) and decreasing groundwater level caused by the growth of built-up areas (1.63%). The analysis indicates the need to regularly monitor the changes and take necessary measures towards water planning.

Sustainable management and allocation of freshwater resources for a large population and growing industries in Visakhapatnam city requires a comprehensive estimate of water withdrawal by each economic sector, including both direct and indirect consumption (Figure 5). The results of analysis using the EEIO model reveal that the total direct water withdrawal used for the primary industry was more than 91%, accounting for 645 million m^3, including crops like paddy rice (75.6 million m^3), sugarcane (95.2 million m^3) and livestock (12.6 million m^3). Apart from agricultural sectors, other significant users include chemical and chemical products (5.4 million m^3); construction and construction services (1.7 million m^3); food products, textiles and drugs and medicine industries (nearly 3.0 million m^3).

On the other hand, the indirect water consumption is higher in manufacturing sectors like chemical and chemical products, standing at 12.2 million m^3 followed by the other critical dominant industries, drugs and medicine, and textiles. With limited available water resources in this district, water planning should focus on the sectors that can consume a significant portion of water both directly and indirectly in the production process, by adopting water-efficient methods and technologies.

Figure 4: Land use and land cover changes in Visakhapatnam, India, from 2006 to 2016

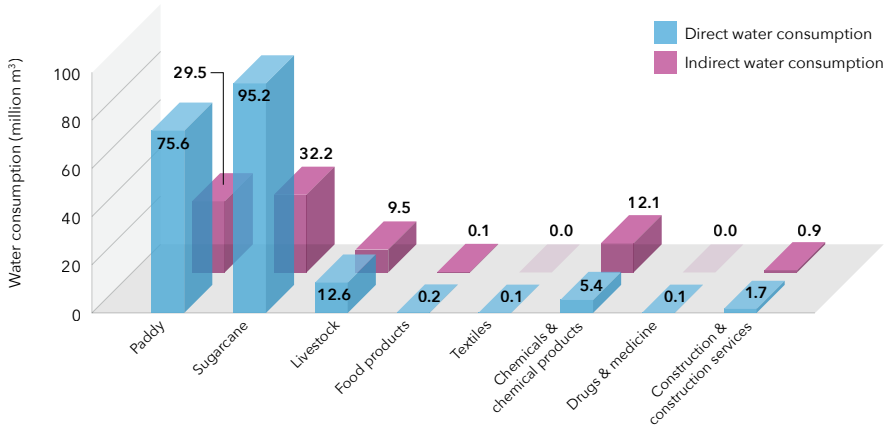


Figure 5: Sector-wise direct and indirect water consumption in Visakhapatnam, India

Rayong Province, Thailand

The Eastern Economic Corridor (EEC) is a special development zone in Thailand aimed at being a regional gateway for trade and investment and advancing the country's economic growth, including developing high-tech industrialised transformation of three provinces – one of which is Rayong province. Rayong has an urban area of 484 km2 and is the second largest in the East region, offering a substantial industrial base for manufacturing establishments (Phuangketkeow, 2020). Figure 6 shows the growth in manufacturing industries from 2014 to 2016, namely food & beverages (19.7%); rubber & plastic (16.7%); leather products, wood and wood products & furniture (14.8%); paper, paper product & printing (10.8%); and transport & others (9.4%) that are targeted industries within EEC. In addition, water demand is expected to increase drastically; cautious water resource management plans are needed to prevent shortages and conflicts over limited resources in the future.

The agricultural industry in Rayong records the highest rate of total direct water use, and the lowest rates of indirect water usage (Figure 7). Among the sectors, para rubber consumes 595.7 million m^3 followed by food crops at 416.2 million m^3 and livestock at 11.8 million m^3. The agricultural sector's total direct water use of approximately 2,621 million m^3 accounts for 92.5%. By contrast, the manufacturing and service sectors present low direct water usage and high indirect water usage, including the sectors of chemical and chemical products (4.5 million m^3); transportation storage (2.5 million m^3); and fabricated metal products (except machinery and equipment) (2.7 million 500 m^3). Direct water consumption is less in these sectors, but they consume products from other sectors, influencing their high indirect water usage. Therefore, new production technology could assist these sectors to increase productivity and reduce water usage.

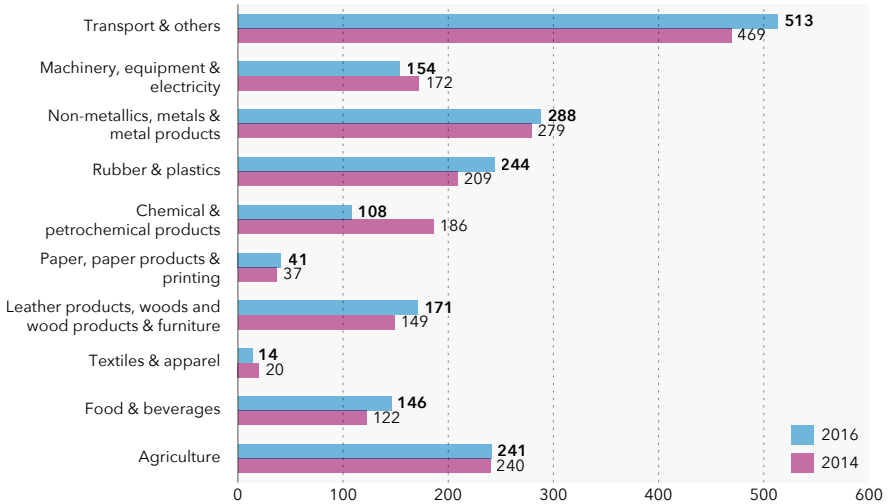


Figure 6: Number of manufacturing industries in Rayong, Thailand, from 2014 to 2016

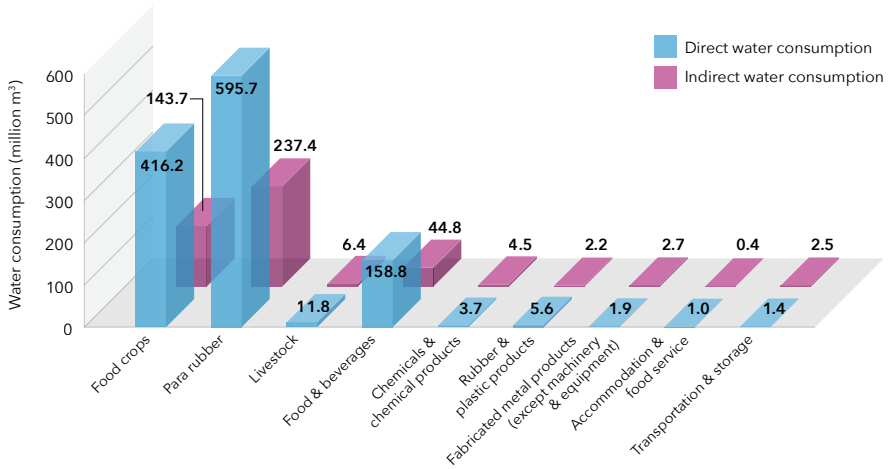


Figure 7: Sector-wise direct and indirect water consumption in Rayong, Thailand

Water Pollution

This section describes the total BOD loads by sector, discharged both directly and indirectly from economic activities in the case studies sites. It illustrates how the pollution loads are influenced by sectoral demand.

Bali Province, Indonesia

Sources of and Causes for BOD

An estimated total of 246,868 tons of BOD was produced in Bali's economy in 2007. Livestock and poultry alone accounted for 96% of the total BOD loads, followed by agriculture, forestry and fishery, and food, beverage, tobacco & coffee industries.

Apart from direct pollution, the livestock and poultry sector performed a dominant role for the indirect BOD discharge. This was due to the self-reliance of the sector for its input requirements. Noticeably, hotels and restaurants, food, beverage, tobacco and coffee industries and fuels, chemical industry, rubber, and plastic produced high levels of BOD indirectly compared to their direct discharge. Among these, hotels and restaurants revealed heavy dependence on other sectors, causing a high level of indirect pollution.

Water Pollution Attributed to Economic Drivers

The discharge of water pollutants increases with sectoral outputs. Hence, water pollution can be controlled by managing the sectoral outputs, which are determined by what we term as 'economic drivers': intermediate and final demands (households, exports and imports). Understanding the relationship between water pollution and the economic drivers is an effective way to control water pollution, however often overlooked. The case study investigated the role of each economic driver in BOD discharge.

In Bali, the intermediate demand caused considerable BOD discharge from the major BOD polluter sectors (livestock and poultry; and agriculture, forestry, and fishing) (Figure 9). As a part of final demand, household demand accounted for over 50% of total BOD for the food, beverage, tobacco, and coffee industries. Similarly, export played considerable roles in releasing BOD from the manufacturing sector (such as fuels, chemical industry, rubber, and plastic) and the service sector (hotel and restaurants).

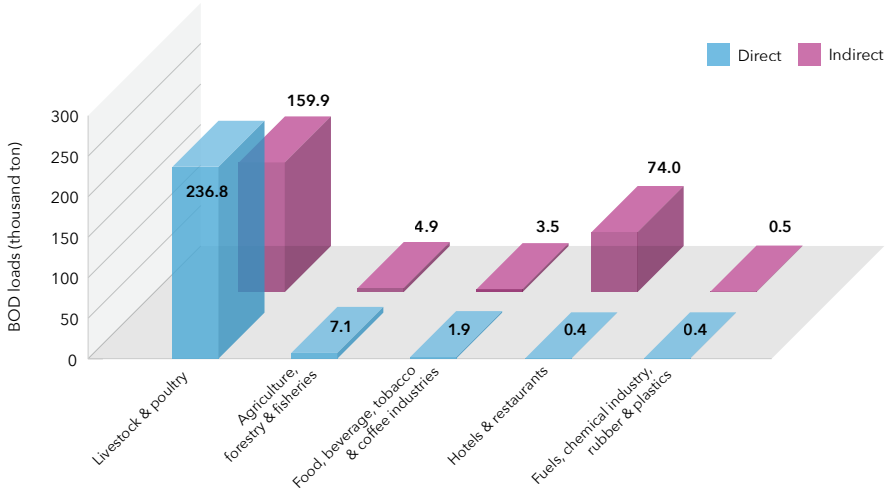


Figure 8: Discharge of BOD loads by major water-polluting sectors in Bali, Indonesia

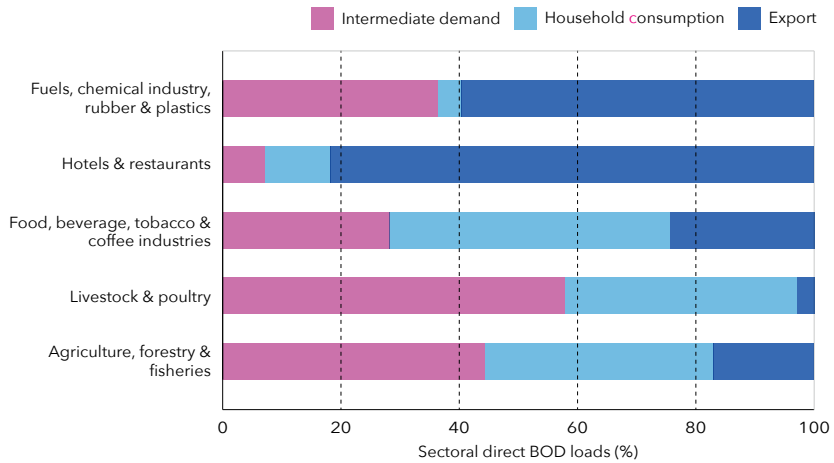


Figure 9: BOD loads (%) corresponding to economic drivers in major water polluting sectors in Bali, Indonesia

Kaski District, Nepal

Sources of and Causes for BOD

An estimated total of 35,049 tons of BOD was generated through Kaski's economic activity in 2011. The top five sectors of high BOD loads are presented in Figure 10. Agriculture, forestry, and fishery (including livestock and poultry) accounted for 99% of the total direct BOD loads, followed by hotels and restaurants, and manufacturing sectors that typically consist of paper and paper products, food and beverage, and rubber industries.

The livestock and poultry sectors were also a major source of indirect BOD discharge, accounting for 59% of total BOD discharge. This high percentage was mainly contributed by their own inputs. In contrast, the food and beverage industry showed high indirect BOD discharge (27%) as compared to 0.1% of direct discharge, indicating that it is dependent upon other, typically more polluting, industries for inputs. Hotels and restaurants caused 3% of total BOD discharge indirectly, about 13 times higher than direct BOD discharge. Similarly, the paper and rubber industries had comparatively low direct BOD releases but played a significant role in indirect BOD releases.

Water Pollution Attributed to Economic Drivers

Figure 11 shows a breakdown of pollution loads (as BOD) associated with intermediate and final demands for selected sectors in Kaski. The intermediate demands are further viewed as own inputs and other sector inputs demand.

A major driver of BOD pollution in most sectors (except the rubber industry) is to meet its final demand, which basically corresponds to *household consumption* in the study area. As for the rubber industry, it has a much higher (almost 80% of total BOD) level linked to intermediate demand, indicating that huge pollution loads discharged by sectors are to be used in other industries as well. Similarly, agriculture, forestry, and fisheries are also in high intermediate demand because raw products from these sectors are used in processing industries.

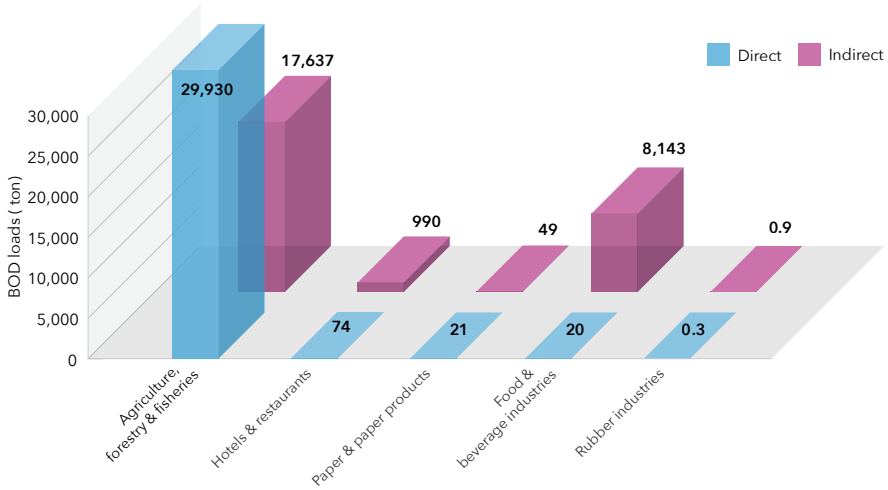


Figure 10: Discharge of BOD loads by major water-polluting sectors in Kaski, Nepal

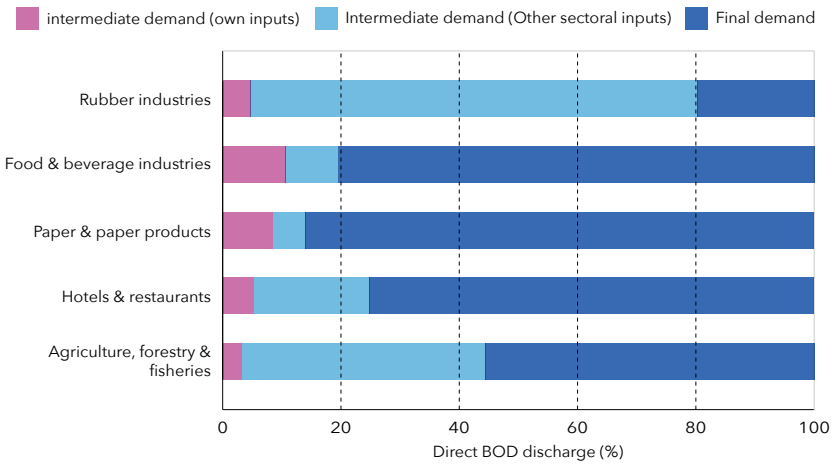


Figure 11: BOD loads (%) corresponding to economic drivers in major water polluting sectors in Kaski, Nepal

Visakhapatnam City, India

Sources of and Causes for BOD

In Visakhapatnam city, economic activities generated an estimated 440,452 tons of BOD in 2015. Figure 12 shows the top BOD discharging sectors in the city. The direct BOD loads from agriculture and livestock collectively accounted for about 80%, with agriculture contributing 32.9% BOD load and livestock generating a 47.1% BOD load. Within the manufacturing industries, chemical and chemical products accounted for 11.1%, while food and beverage and basic metal industries contributed 1.2% and 0.9%, respectively.

Besides the direct BOD discharge, a significant portion of the indirect BOD discharge was also produced by the livestock sector, accounting for 35.7% of total indirect BOD discharge (Figure 12). Agriculture generated 11.4% of total indirect BOD discharge. A large share of indirect BOD loads is attributed to agriculture and livestock, indicating the sector's dependence on its own input requirements. Drugs and medicines industries contributed only 0.9% direct discharge, but it had a high indirect BOD discharge (15.3%), indicating a huge dependency of the sector on other sectors in acquiring inputs. Noticeably, the construction sector does not produce BOD directly but contributed 7.6% to total BOD discharge indirectly. A high proportion of indirect BOD emissions from the construction sector is due to the need for raw materials from other sectors.

Water Pollution Attributed to Economic Drivers

Figure 13 illustrates the pollution loads (as BOD) associated with selected sectors' intermediate and final demands. The intermediate demands linked to BOD loads are further subdivided into BOD loads with own inputs and other inputs.

For most sectors (except rubber and plastic products, and basic metal industries), BOD pollution is primarily driven by the final demand, which corresponds to household consumption in the study area. Two sectors (rubber and plastic products; basic metal industries) have a much higher level of intermediate demand (almost 60% of total BOD), which indicates the product will be used in other industries as well. Also, agriculture (crops) and livestock had a relatively high intermediate derived BOD (%), highlighting the close relationship due to raw products from these sectors being used in other industries.

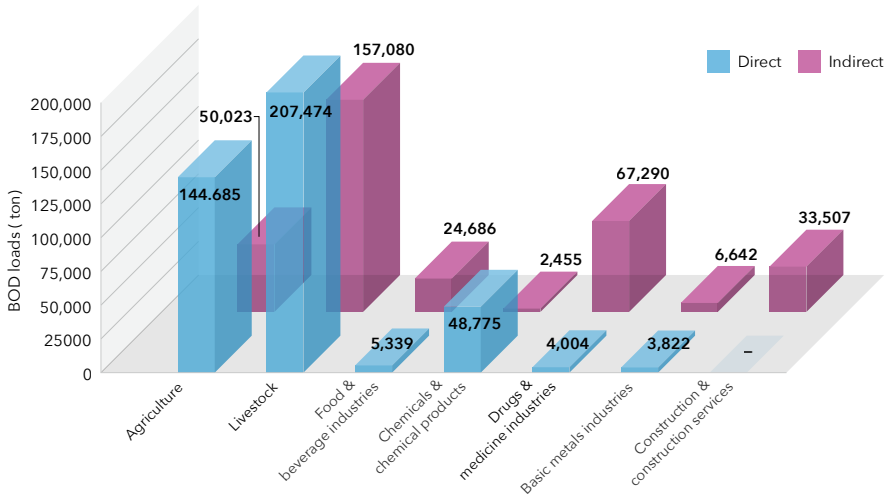


Figure 12: Discharge of BOD loads by major water-polluting sectors in Vishakhapatnam, India

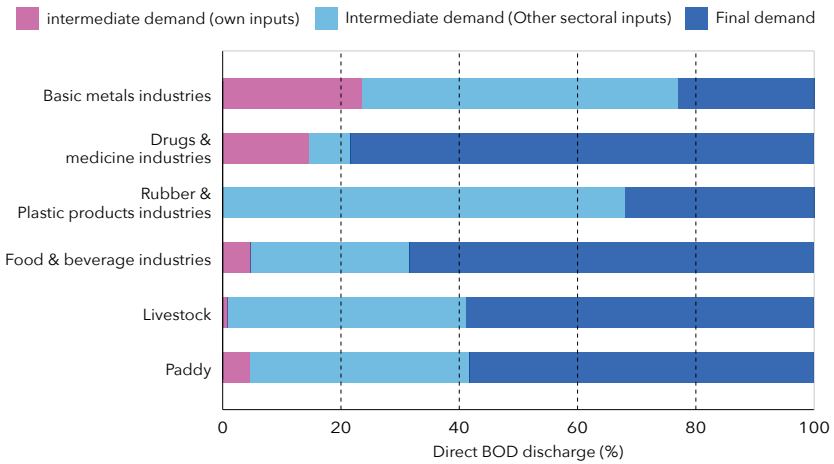


Figure 13: BOD loads (%) corresponding to economic drivers in major water polluting sectors in Vishakhapatnam, India

Rayong Province, Thailand

Sources of and Causes for BOD

In Rayong province, economic activity generated an estimated 33,558 tons of BOD in 2015. The top BOD discharging sector is depicted in Figure 14. It shows that BOD loads from agriculture (food crops, rubber plants) and livestock collectively accounted for about 77.5%, with agriculture contributing a 25.86% BOD load and livestock generating a 51.65% BOD load. Manufacturing industries accounted for 18.54% of total BOD, whereas food and beverage industries only accounted for 13.99%.

A significant portion of indirect BOD discharge was also produced by the livestock sector, accounting for 46.41% of total indirect BOD discharge. Agriculture (food crops and rubber plantations) generated 14.32% of total indirect BOD discharge. A large share of indirect BOD loads is attributed to agriculture and livestock, indicating the sector's dependence on its own input requirements. Despite only 0.62% direct discharge, the rubber and plastic products industry had a high indirect BOD discharge (8.17%), indicating that the sector depends on inputs mainly from the rubber plants. Moreover, the food and beverage industries contributed 13.94% and 18.20% to BOD discharge directly and indirectly, respectively. A high proportion of indirect BOD emissions is due to the need for raw materials from other sectors.

Water Pollution Attributed to Economic Drivers

Figure 15 illustrates the pollution loads (as BOD) associated with selected sectors' intermediate and final demands. Moreover, to view the BOD discharged to satisfy own or other sectoral inputs requirements, the intermediate demands are further subdivided into own inputs and other inputs. For most sectors (except rubber plantations and paper and paper products industries), BOD pollution is driven mainly by the need to meet the final demand, which corresponds to household consumption in the study area. Rubber plantations have a much higher level of intermediate demand (almost 80% of total BOD), which indicates the product will be used in other industries as well. Also, agriculture (crops) had a relatively high intermediate derived BOD (%), which highlights the supply of raw products from these sectors to other sectors, mainly processing industries.

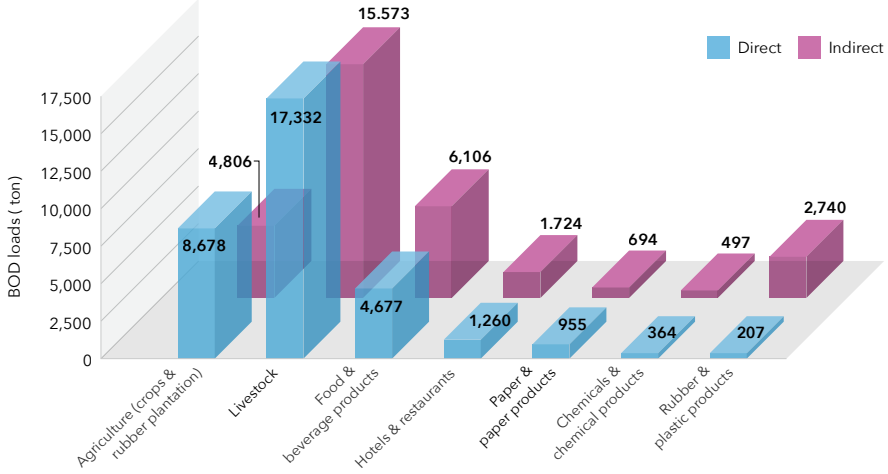


Figure 14: Discharge of BOD loads by major water-polluting sectors in Rayong, Thailand

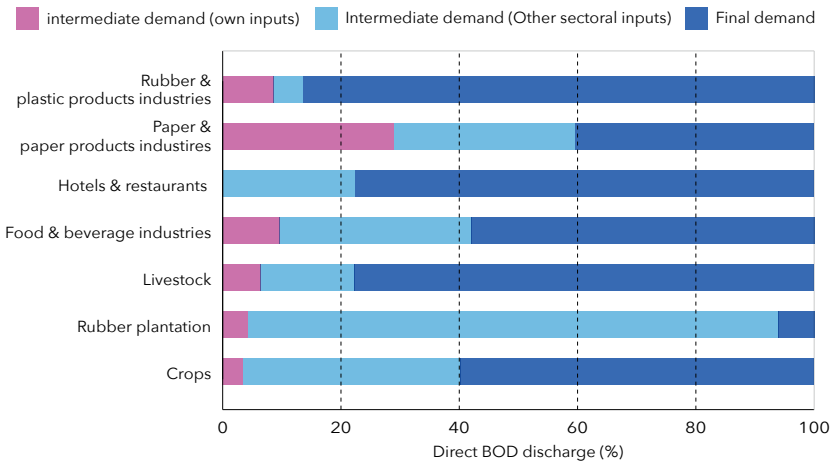


Figure 15: BOD loads (%) corresponding to economic drivers in major water polluting sectors in Rayong, Thailand

Findings Summary

In general, the analysis of pollution load with economic drivers revealed that final demand, dominated by household demands, plays a significant role in water pollution. To minimise pollution, lowering the demand, which in turn reduces outputs from high-polluting sectors, could be considered. The best approach to reducing household consumption would include changing dietary habits (e.g. switching to environmentally sustainable foods). Such changes may take time, nevertheless, starting such an initiative would significantly improve pollution control in the long term.

In the case of Bali, the export of some items has also contributed to BOD discharge. In cases like these, reducing exports might offer an alternative, although socio-economic aspects should be carefully considered for such decision-making.

The intermediate demand also causes significant quantities of BOD to be released from certain industries, such as rubber plantations. In order to minimise the pollution loads in these industries, several alternatives can be sought, such as recycling rubber and improving rubber cultivation practices focusing on land selection and fertiliser management.

Impact Analysis

The impact analysis (IA) is vital for considering policy scenarios in assisting water planners with future projections. It is also a valuable instrument for water policymakers to integrate water-economic research. The following case studies provide an IA that describes a change of 20% to 30% in the final demand and evaluates its consequence on added value and total water use in the selected economic sectors.

Scenario 1:

Effects of an increase by 25%~30% of the final demand in selected sectors and economic benefits of water use.

Scenario 2:

Effects of sectoral growth on water pollution of an increase by 20% of the final demand in selected sectors.

Scenario 1: Effects of an increase by 25%~30% of the final demand in selected sectors and economic benefits of water use.

Bali Province, Indonesia

Increasing the final water demand of the food, beverage, and tobacco industry (FB&T) by 20% would significantly impact several other sectors, predominantly rice, maize, livestock and other food crop sectors that serve as inputs for the FB&T sector. The scenario increases total additional water use by 2.99%, with an extra overall added value of IDR 198,523 million.

For the FB&T sector, the total use of water increased by 13.36% (8.8 million m³). Similarly, the most prominent sectors, paddy rice, 12.47% (111.4 million m³) and maize, 3.67% (43.3 million m³), would also increase water use that supports the FB&T sectors (Figure 16).

From the same scenario, the environmental cost in terms of water use gives an additional water demand of 178.2 million m³ for an additional economic benefit of the added value of FB & T sector.

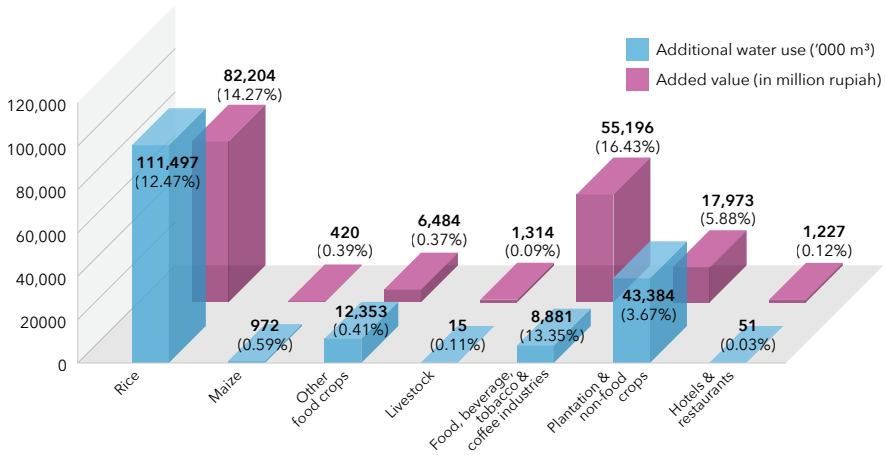


Figure 16: Effects of an increase by 20% of the final demand in selected sectors in Bali, Indonesia

Kaski District, Nepal

Increasing the final demand for the agriculture, forestry and fishing (AF&F) sector by 30% would significantly impact several other industries, predominantly chemicals and chemical products, beverages, rubber and plastic products, and food products that serve as inputs for the AF&F sector. This scenario increases total additional water use by 13.3%, with an extra overall added value of NPR 254 million.

For the AF&F sector, the total use of water increased by 16.0% (21,233 thousand m³). Likewise, key sectors like chemicals and chemical products, 8.2% (0.3 thousand m³); beverages, 4.5% (4 thousand m³); rubber and plastic products, 1.5% (0.07 thousand m³) and food products, 0.8% (1 thousand m³) increased their water consumption to support the AF&F sectors (Figure 17).

From the same scenario, the environmental cost of water use gives additional water of 21.4 million m³ for an additional economic benefit of the added value of the AF & F sector.

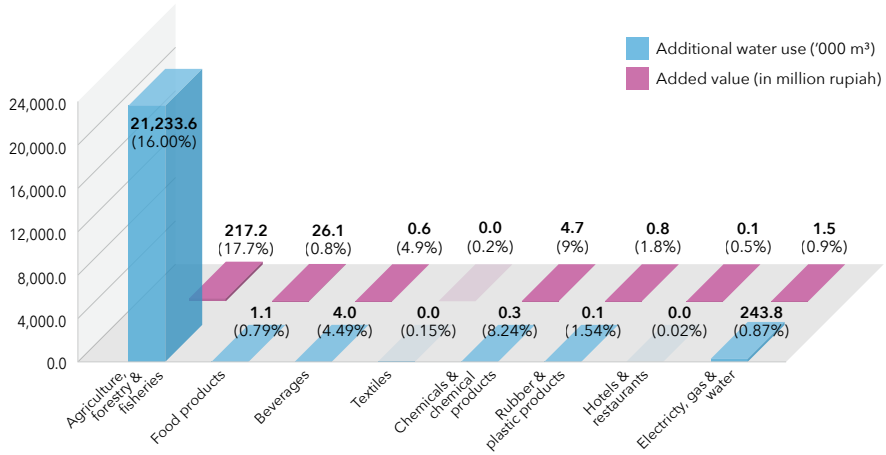


Figure 17: Effects of an increase by 30% of the final demand in selected sectors in Kaski, Nepa

Scenario 1: Effects of an increase by 25%~30% of the final demand in selected sectors and economic benefits of water use.

Visakhapatnam City, India

The increase in the final demand of the drugs and medicine sector by 25% would significantly impact several other sectors, such as chemicals and chemical products, fruits, textiles, food products, and livestock that serve as inputs for the drugs and medicine sector. The scenario increases total additional water use by 2.2%, with an extra overall added value of INR 4,899 million.

In Figure 18, the total use of water for the drugs and medicine sector increased by 23.2% (3.4 ten thousand m^3). To support the drugs and medicine sectors the other sectors like chemicals and chemical products, 13.4% (234.0 ten thousand m^3); fruits, 3.7% (17.1 ten thousand m^3); textiles, 4.0% (0.4 ten thousand m^3), food products, 3.1% (0.8 ten thousand m^3) and livestock, 2.3% (50.2 ten thousand m^3) increased their water consumption respectively.

From the same scenario, the environmental cost of water use gives an additional water demand of 2,420 ten thousand m^3 for an additional economic benefit of the added value of the drugs and medicine sector.

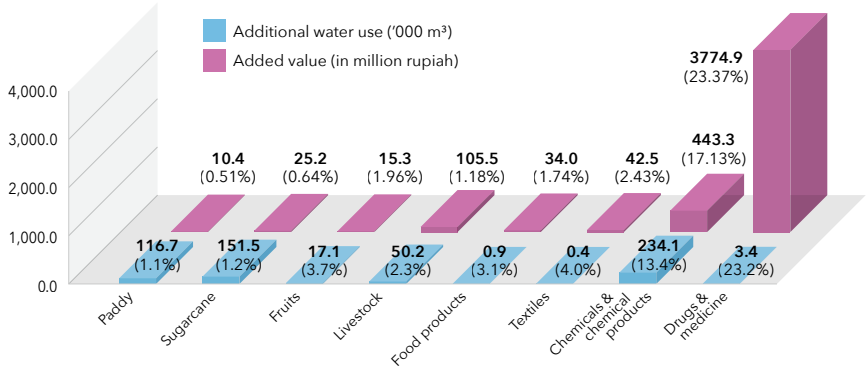


Figure 18: Effects of an increase by 25% of the final demand in selected sectors in Visakhapatnam, India

Rayong Province, Thailand

Increasing the final demand of the food and beverages sector by 25% would significantly impact several other industries, such as food crops, other crops and livestock that serve as inputs for the food and beverage sector. The scenario increases total additional water use by 3.4%, with an extra overall added value of THB 1,072 million.

The total water use for the food and beverage sector increased by 15.2% (3,096 ten thousand m^3). Similarly, key sectors like food crops, 7.9% (4,397 ten thousand m^3), other crops, 2.5% (4,719 ten thousand m^3) and livestock, 3.2% (58.5 ten thousand m^3) also increased water consumption to support food and beverage sectors (Figure 19).

From the same scenario, the environmental cost of water use gives additional water of 12,339 ten thousand m^3 for an additional economic benefit of the added value of the food and beverage sector.

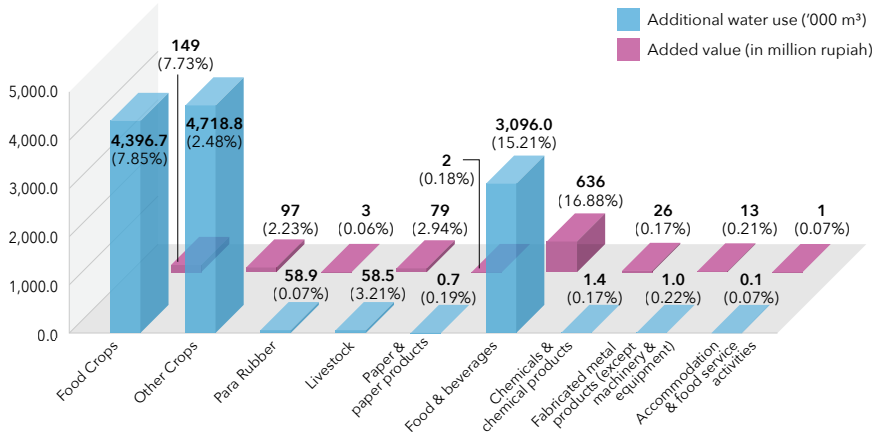


Figure 19: Effects of an increase by 25% of the final demand in selected sectors in Rayong, Thailand

Scenario 2: Effects of sectoral growth on water pollution of an increase by 20% of the final demand in selected sectors.

Bali Province, Indonesia

Impact of sectoral growth on water pollution

An EEIO provides the ability to establish a relationship and to project pollution loads for future growth. Here is an example of comparing pollution load (BOD) among three selected major sectors' growth by 20% increment in final demand.

Under the 20% increment of final demand, the three selected sectors, namely livestock and poultry, food, beverage, tobacco, and coffee industries, and hotel and restaurants, increase the BOD loads at different levels (Figure 20 and 21). For instance: livestock and poultry contribute to a high BOD discharge, which increases the BOD loads by 13.5% within the sector and 13.0% in the overall economy (Figure 20). Food, beverage, tobacco, and coffee industries show the least impact on overall BOD discharge (0.3%) despite a 14.2% increase within the sectoral BOD discharge. Hotels and restaurants increase the BOD loads for both, i.e., within the sector and overall economy by 19.0% and 6.3%, respectively (Figure 20).

Kaski District, Nepal

Figures 22 and 23 show that agriculture, forestry, and fishery contribute to a high BOD discharge, which increases the BOD loads by 11.8% within the sector and 11.7% in the overall economy. The close values for both within and overall sectors is thus due to sectoral dominance in the economy and its heavy reliance on its own sector for production. The food industry increases the BOD loads by 18.8% and 5.4% within the sector and in the overall economy. Hotels and restaurants sectors increase BOD for overall sectors by 17 times and the food industries by 442 times compared to their increment within the sector. Hotel and restaurants discharge BOD with 0.7% increment for overall sectors but 16.1% within sectoral BOD discharge.

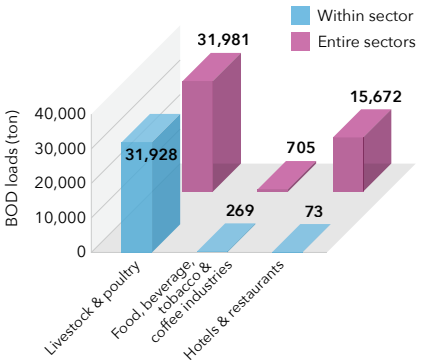


Figure 20:
Increased BOD loads within the sector and the entire sectors under 20% increase of final demand of the selected three-sectors in Bali, Indonesia

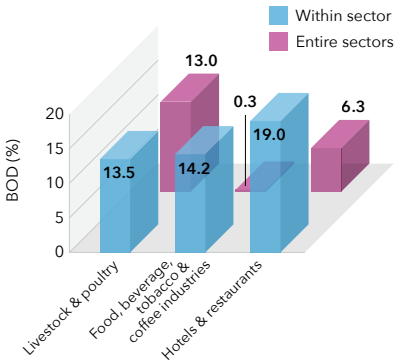


Figure 21:
Increased BOD loads percentage within the sector and the entire sectors under the 20% increase of final demand of the selected sectors in Bali, Indonesia

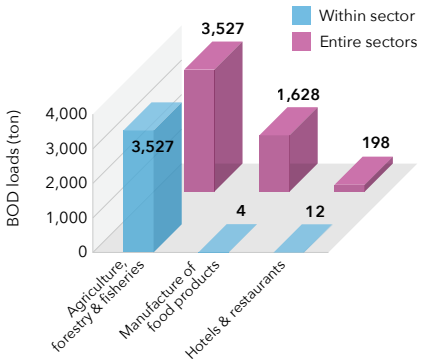


Figure 22:
Increased BOD loads within the sector and the entire sectors under 20% increase of final demand of the three selected sectors in Kaski, Nepal

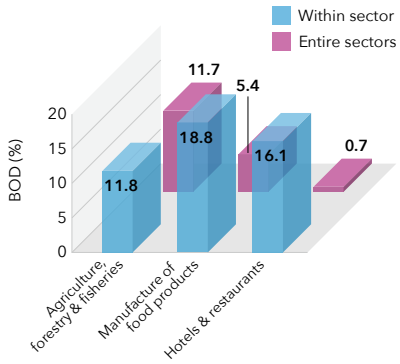


Figure 23:
Increased BOD loads percentage within the sector and the entire sectors under the 20% increase of final demand of the selected sectors in Kaski, Nepal

Scenario 2: Effects of sectoral growth on water pollution of an increase by 20% of the final demand in selected sectors.

Visakhapatnam City, India

The increase in the final demand (20%) has different impacts on sectoral BOD discharge. Figures 24 and 25 show livestock increases BOD loads by 11.9% within the sector and 7.1% of the whole economy. Similarly, food industries increase BOD loads by 12.7% within their sector and by 0.9% overall. In drugs and medicines, the BOD discharge increased by 3.1% overall but by 18.6% within the sector. Comparatively, growth in the livestock sector causes high increases of BOD loads, both within the sector and the entire sector. A relatively small quantity of BOD load is produced by the food and medicine industries within the sector, but a considerable amount is generated across all industries due to their greater indirect pollution role. For the future growth of these sectors, attention needs to be directed to pollution control both within and beyond the sector.

Rayong Province, Thailand

The potential BOD loads caused by the increase in the final demand of selected sectors by 20% is depicted in Figures 26 and 27. Livestock increases BOD loads by 16.8% within the sector and 9.3% in the entire economy. Similarly, food and beverage industries increase BOD loads by 13.5% within the sector and by 3.6% overall. In hotels and restaurants, the BOD discharge increased by 1% for overall sectors but by 15.5% within the sector. Comparatively, expansion in the livestock sector causes high increases of BOD loads, both within the sector and the entire economy. A relatively small quantity of BOD load is produced by the food and beverage industries within the sector, but a considerable amount is generated across all industries due to their greater indirect pollution role. As with the case for the Vishakhapatnum city in India, attention needs to be directed to pollution control both within and beyond the sector to achieve growth in the future.

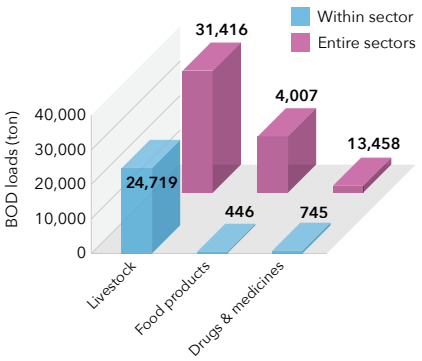


Figure 24:
Increased BOD loads within the sector and the entire sectors under 20% increase of final demand of the three selected sectors in Visakhapatnam, India

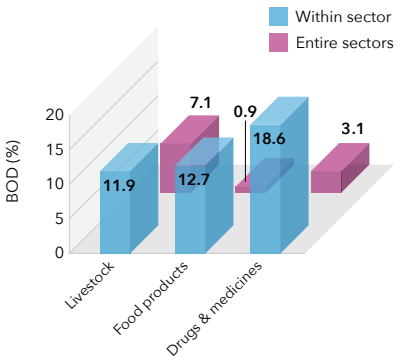


Figure 25:
Increased BOD loads percentage within the sector and the entire sectors under the 20% increase of final demand of the selected sectors in Visakhapatnam, India

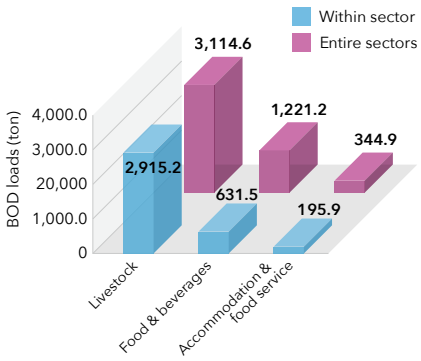


Figure 26:
Increased BOD loads within the sector and the entire sectors under 20% increase of final demand of the three selected sectors in Rayong, Thailand

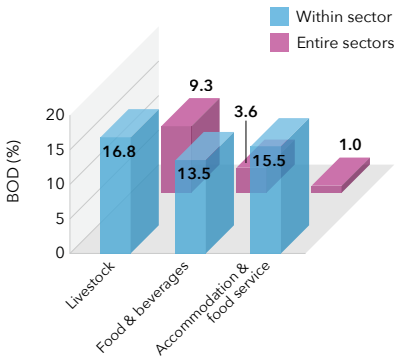


Figure 27:
Increased BOD loads percentage within the sector and the entire sectors under the 20% increase of final demand of the selected sectors in Rayong, Thailand

Social Dimension of Water Problems in Kaski, Nepal: Stakeholders' Perceptions

To validate the WSD analysis on the relationship between water and pollution in the economy, WSD conducted a questionnaire survey in Kaski District in Nepal with the following objectives: i) evaluate stakeholders' perceptions of the local water quality and quantity; and ii) examine stakeholders' views on WSD's case study's major findings and policy measures.

A total 46 stakeholders from i) hotel and tourism (n=10) ii) manufacturing industries (n=10) iii) agriculture sector/livestock farming (n=10) iv) residents (n=10), v) government (n=3), and iv) university (n=3), were selected and surveyed.

Seventeen questions related to water issues were asked, for which key results are discussed below:

1) In response to the question, *"Is there any problem with access to water in the area in the last 10-15 years?"*, the opinions were divided mainly between the stakeholders who believed that access to water (water quantity) had been a problem for a decade, and those who disagreed with the statement. Among all respondents, the tourism sector reported the greatest difficulty in acquiring sufficient water. Some participants from agriculture and tourism answered they did not know whether the availability of water is diminishing or not in the area (Figure 28).

2) Unlike water quantity, nearly all stakeholders from all fields recognised the significant increase in water pollution in the last 10-15 years (Figure 29).

3) A majority of participants strongly agreed that government initiatives to control water pollution were ineffective. However, some respondents belonging to residents and agriculture groups were not aware of the roles and initiatives of the government in preserving water quality (Figure 30).

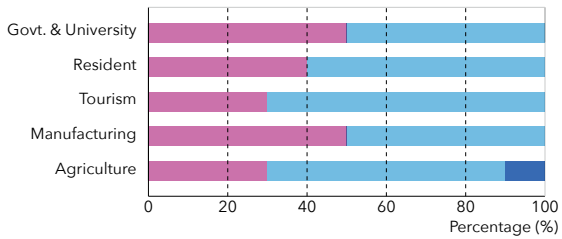


Figure 28: Comparison of stakeholders' perceptions related to water quantity as *"access to water became difficult during the last 10-15 years"*

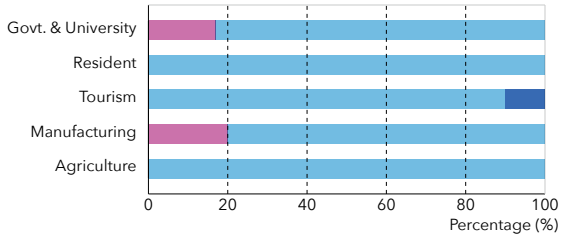


Figure 29: Comparison of stakeholders' perceptions related to "*water quality having deteriorated in the last 10-15 years*"

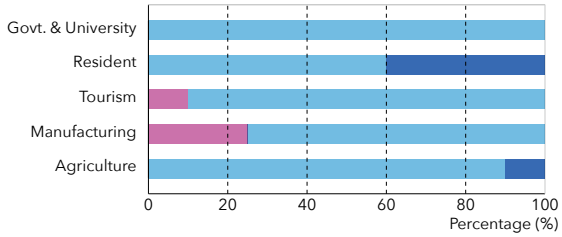


Figure 30: Response of stakeholders on "*government initiatives to control water pollution have not yet been effective*"

Agree Disagree Do not know

4) Regardless of their category, the majority of respondents agreed that policies on recovering animal waste and processing it into a useful product (such as: biogas, composting, animal feedstuffs) would be the best option to reduce water pollution from livestock and poultry, which are the major polluters (Figure 31).

5) When we asked about the introduction of a polluter pays model (e.g., wastewater discharge fees that increase with pollution loads) for water pollution control, almost all respondents agreed with it. It reflects their concern about the deteriorating water quality and willingness to pay to preserve the environment. Despite the polluter pays model, we demonstrate in our analysis that a set of pollution control measures specific to each sector must be introduced to effectively implement policy (Figure 32).

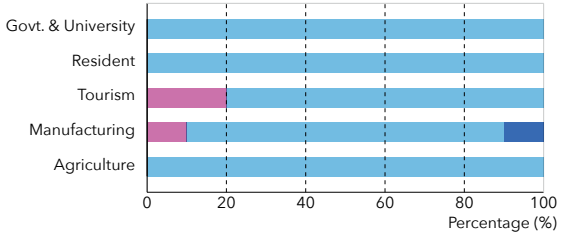


Figure 31: Response of stakeholders on *"A policy of recovering animal waste and turning it into a valuable product (such as: biogas, composting, animal feedstuffs) would be the best option to reduce the livestock and poultry waste derived water pollution"*

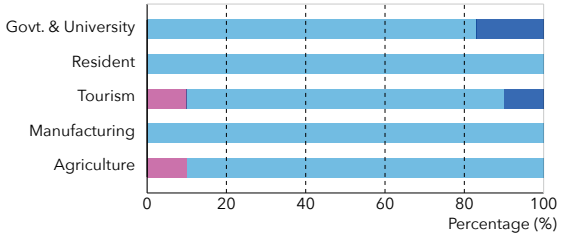


Figure 32: Stakeholders' views on "*introduction of a polluter pays model (e.g., wastewater discharge fees that increase with pollution loads) for water pollution control*"

Agree Disagree Do not know

The study clearly showed that stakeholder awareness about major water issues and water quality was given top priority in Kaski district, regardless of the sector in which they were involved. However, earlier efforts for protecting water quality have not been effective, highlighting the need for a proper water pollution control policy. It was also confirmed that stakeholders' perceptions and views on their water environment align with the results and findings from WSD research.

Conclusions and Policy Implications

- As expected, the direct water consumption for agriculture sectors was high in all case studies. Likewise, the manufacturing and services sectors consume a large amount of water indirectly.

- To improve water use efficiency in the agricultural sector that consumes the largest amount of water of all economic actors, solutions could be provided through developing water-saving agriculture, controlling erosion and landslide management systems, preventing floods, reducing leakages in the drainage system, and adopting water-saving technologies, such as drip irrigation systems in locations with raw water.

- For tourism (e.g., hotels and restaurants) and other manufacturing sectors, quota water supply, paid water supply, and double charging can be implemented for industries that overuse groundwater sources. Alternatively, the industries' development of small-scale water storage reservoirs will reduce dependence on resources from water sources like rivers and groundwater.

- Water stakeholders should meet and review the water demand and supply regularly. Innovative ideas and adopting water-use saving technologies should be shared and promoted to benefit others and serve the interests of society and the environment.

- National, regional and local level water budgeting tables and EEIO analysis would offer an effective tool for policymakers to understand the distribution of water resources for economic activities and prevent social conflicts among water users.

- Our study revealed livestock and poultry sectors as the major source of water pollution (BOD discharge), requiring attention to the activities of this sector.

- The practice of handling and treating livestock waste is not common. A policy of turning animal waste into a valuable product (such as: biogas, manure) would be the most effective way to recover the resources and to control water pollution. Waste from poultry farms, which is growing rapidly, is either composted or is used for animal feedstuffs. There are technical and financial barriers in implementing these practices in the real world, where policy could assist by providing financial and technical incentives.

- Manufacturing (such as food and beverages, chemical industry, rubber and plastics industry, and metal industry) has also been a major contributor of water pollution; cleaner production and wastewater treatment practices should be implemented for direct pollution control. Similarly, service sector waste (hotels and restaurants) can be better handled by expanding the capacity of wastewater treatment plants and complying with discharge standards.

- As a unique study, WSD research provides policy directives for controlling water pollution by analysing how sectoral outputs in the economy contribute to water pollution. For instance: the total output consists of the intermediate and final demands of the economy, while the final demand is further set by exports, households and gross stock. Managing the demand of high polluting sectors is an effective way to curb water pollution.

- Taking indirect pollution into account, hotels and restaurants (in the case of Bali in Indonesia, Kaski in Nepal, and Rayong in Thailand) and the construction sector (Visakhapatnam, India) have played a significant role in water pollution. Aside from focusing on the premises of hotels and restaurants (the traditional approach), policy should also seek and prioritise water pollution control on the supply-side (indirect pollution). This study provides a strong evidence and basis for levying environmental tax from service sectors and offsetting the high investment cost for the livestock sector.

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