Shaping Brazilian water policy using Environmentally Extended Input-Output Matrix

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*The contents of this publication express the views of the authors and do not necessarily represent the views of ANA.
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RESUMO
O Brasil abrange 12% da água doce disponível no mundo, apresentando balanço hídrico confortável. No entanto, existe uma distribuição regional desigual deste recurso no país. Esse aspecto aliado às mudanças climáticas e à modificação do uso do solo intensificam os problemas de segurança hídrica nas bacias hidrográficas brasileiras. Nesse contexto, a demanda por informações sobre a utilização, direta e indireta, de água ao longo da cadeia de produção aumentou. Os objetivos deste artigo são: (i) identificar os principais usuários de água (diretos e indiretos); e (ii) estimar o impacto do volume de água incorporado nos fluxos de comércio sobre o balanço hídrico em bacias hidrográficas brasileiras. A metodologia utilizada refere-se à Matriz Insumo-Produto Ambientalmente Estendida e ao Sistema de Contas Econômicas Ambientais da Água. Numa perspectiva inter-regional, estimou-se a Matriz Insumo-Produto para 2 bacias hidrográficas brasileiras mais o Resto do Brasil e 24 atividades econômicas para o ano de 2017. Os resultados mostraram que o balanço hídrico da bacia hidrográfica do Rio Grande se encontrava em situação preocupante, com 12,6% dos 744,28 m³/s de disponibilidade hídrica destinados à demanda para usos consuntivos (93,9 m³/s), sendo que parte relevante desse uso foi destinada à produção de bens e serviços exportados para outras regiões e/ou países (75 m³/s, ou 10,1% da disponibilidade hídrica). Os principais setores usuários de água – (i) Agricultura; (ii) Abastecimento de água, coleta de esgoto e tratamento de resíduos; e (iii) Fabricação de açúcar (responsável por 80% da captação de água na bacia) – foram responsáveis por apenas 10% do valor agregado e 20% do emprego na região. Ao mesmo tempo, o balanço hídrico da bacia hidrográfica do Rio Paraíba do Sul apresentava situação confortável, com 8,9% da disponibilidade hídrica comprometida com a vazão de retirada para uso consuntivo. Da mesma forma, a procura de fora da bacia foi a principal impulsionadora do uso da água, e o principal setor em termos de captação de água (Água, esgotos e gestão de resíduos, 71%), contribuiu com apenas 3% do valor agregado e empregado na região.

PALAVRAS-CHAVES: Modelo Insumo-Produto, Sistema de Contas Econômicas Ambientais, bacia hidrográfica.

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ABSTRACT
Brazil encompasses 12% of fresh water available in the world, presenting a comfortable water balance. However, there is an uneven regional distribution of this resource in the country. This aspect combined with the climate change and land use modification intensify the water security problems in the Brazilian river basins. In this context, the demand for information on direct and indirect water use along the supply chain has been increased. The objectives of this article are: (i) to identify the main water users (direct and indirect); and (ii) estimate the impact of the water volume embodied in trade on the Brazilian river basin's water balance. The methodology used refers to the Environmentally Extended Input-Output Matrix and System of Environmental Economic Accounting for Water. From an interregional perspective, the input-output matrix was estimated for 2 Brazilian river basins plus the Rest of Brazil and 24 economic activities to the year 2017. The results showed that the water balance of the Grande River Basin was in a worrying situation, with 12.6% of the 744.28 m^3/s of water availability committed to the demand for consumptive uses (93.9 m^3/s), and a relevant part of this consumptive use was destined to the production of goods and services exported to other regions and/or countries (75 m^3/s, or 10.1% of water availability). The highest consumptive water user sectors – (i) Agriculture; (ii) Water supply, sewage collection and treatment waste management; and (iii) Sugar manufacturing (responsible for 80% of water abstraction in the Basin) – accounted for only 10% of value added and 20% of employment in the region. At the same time, the water balance of the Paraíba do Sul river basin was in a comfortable situation, with 8.9% of the water availability committed to the withdrawal flow for consumptive use. Similarly, demand from outside the basin was the main driver for water use, and the main sector in terms of water abstraction (Water, sewage and waste management, 71%), contributed with only 3% of value added and employed in the region.

KEYWORDS: Input-Output Model, System of Environmetal-Economic Accounting, watershed.

JEL: C67, D57, Q56

INTRODUCTION

One of the biggest challenges of the 21st century refers to the sustainable management of water resources. According to the World Bank (2024), the world population in 2020 was 7.95 billion people. According to United Nations – Water (UN-Water, 2021), 2.3 billion people, about 30% of the world's population, live in countries with freshwater shortage. And nearly half of the global population already lives in potentially water-scarce areas for at least one month a year, could increase to around 4.8 and 5.7 billion by 2050 (Burek et al. 2016).

Although the planet's water volume remains more or less constant over the years due to the hydrological cycle, the freshwater availability is not unlimited at the regional level and may be restricted for a period of time (for example, in some months of the year).

Population growth, rural exodus, growing demand for water intended for food production, domestic and industrial use, its pollution and climate change are some of the causes of the growing pressure on this resource.

Globally, Brazil is in a privileged position, concentrating 12% of all the freshwater available in the world, with a comfortable water balance. However, there is an uneven spatial distribution of this resource in the country. About 80% of its availability is concentrated in the Amazon Hydrographic Region, where there is a low population, and the water demand is consequently less intense. At the same time, the greatest demand for water is in the Hydrographic Region of Paraná, which has less than 7% of the national water availability (Ministry of the Environment (MMA), 2006). In turn, such characteristics associated with strong economic concentration have caused some regions to face scenarios of water restrictions.

In this context, it is important to study the freshwater use. It is usually possible to find information on the direct water use, such as for irrigate crops and population water supply. The National Water and Sanitation Agency of Brazil (ANA) provides information on the direct withdrawal, consumption and return of Blue Water[8] for consumptive uses[9] by economic activity and municipalities[10].

However, interest in natural resources indirect use has currently grown. The water indirect use refers to the water volume used to produce inputs for goods and services intended for final consumption. That is, the water indirect use concerns the so-called embodied water. The concept of Water Footprint follows from this reasoning.

According to Hoekstra et al. (2011), the Water Footprint refers to the water volume used to produce a good or service. It's measured along the supply chain, through which the water type is known, as well as where and when it was used.

From the mapping of water use along the supply chain, it is possible to identify the main agents, on the supply side and on the demand side, responsible for water use. By combining these data with information on water availability, it is possible to identify the main agents, also both on the supply side and on the demand side, who are responsible for the water use from water restrictions regions.

In a globalized world where the production and consumption take place in different regions and countries, this type of result is important to improve and development of incentive mechanisms towards the sustainable water use.

In turn, to estimate the Water Footprint, it is necessary to calculate the Virtual Water flow. The Virtual Water concept is similar to the Water Footprint but is generally associated with the water flow embedded in products traded between different regions (Allan, 1993). In

[8] Water available in surface and underground water bodies (Hoekstra et al. 2011).
[9] The water use is considered consumptive when the withdrawn water is consumed, partially or totally, in the process for which it is intended, not returning directly to the water body (ANA, 2019b).
[10] https://www.snirh.gov.br/

this way, if a nation or region exports or imports a good, it is also exporting or importing water associated with this good.

Therefore, the objectives of this article are: (i) to identify the main water users (direct and indirect); and (iii) estimate the impact of the water volume embodied in trade on the river basin's water balance.

MATERIALS AND METHODS

For estimating the Water Footprint and Virtual Water flows, two main approaches are used in the literature, the so-called bottom-up and top-down approaches.

Estimates of Water Footprints based on the first approach are given through Life Cycle Analysis (LCA). These, in turn, are based on detailed information regarding the volume of Virtual Water incorporated in each stage of the individual production processes. However, they do not map the entire supply chain and do not identify product users. Thus, it is not possible to identify the main agents responsible for the total water use in the economy (Feng et al. 2011).

The top-down approach refers to analyzes based on the Input-Output Matrix (IOM), through which it is possible to calculate the Water Footprints along the entire supply chain – whether regional, national or global – so that the water volume used in production is allocated to final consumers. Thus, it is possible to identify the main agents responsible for the total water use in the studied economy (Feng et al. 2011).

From the mid to late 1990s, there was a significant increase in interest in environmental input-output modeling, and there was a large increase in the number of peer-reviewed journal articles on the subject (Hoekstra, 2010). This increase coincided with a growing interest in and availability of data on the System of Environmental-Economic Accounting (SEEA).

The SEEA is a framework that integrates economic and environmental data to provide a more comprehensive and multipurpose view of the interrelationships between the economy and the environment, as well as between the stocks and changes in stocks of environmental assets, as they bring benefits to humanity. It follows a similar accounting structure as the System of National Accounts (SNA). The framework uses concepts, definitions and classifications consistent with the SNA in order to facilitate the integration of environmental and economic statistics.

Among its thematic areas, the SEEA-Applications and Extensions (UN, 2017) points out that the use of the EE-IOT allows the calculation of Water Footprints and Virtual Water flows over the along the entire supply chain, making it possible to identify the main agents responsible for the water use (Feng et al. 2011). In turn, to create an EE-IOT, the Input-Output table is then augmented using data on environmental flows by industry, which can be taken from the SEEA.

Using data on natural input and waste streams from the SEEA is advantageous for compiling the EE-IOT, as the information will already have been organized consistently with the classifications (eg for products or industries).

Considering the objectives of this article and a relevant spatial focus for the management of water resources in Brazil, the top-down approach proved to be more appropriate.

Interregional input-output matrix for Brazilian watersheds

To employ the method proposed, the first step was to disposal the interregional IOM for Brazilian watersheds to the most recent year possible, according to the model showed in following equations.

$$x = (I - A)^{-1} y \qquad \text{Equation (1)}$$

$$L = (I - A)^{-1} \qquad \text{Equation (2)}$$

$$A = Z\hat{x}^{-1}$$ Equation (3)

Where:
x: column vector of gross output.
I: identity matrix.
A: matrix of direct technical coefficients.
L: inverse Leontief matrix.
Z: matrix of intermediate flows.
$\hat{x}^{-1}$: Inverse of the diagonalized matrix of the gross output column vector.

To attend this requirement, we started from the matrix estimated by Visentin and Guilhoto (2019), which refers to year 2009, 50 economic activities and 56 hydrographic basins of the National Water Resources Plan (PNRH) and updated it to year 2017. In this process, we updated the transactions matrix Z according to RAS procedure, described in Miller and Blair (2009) and below.

Designating the base-year transaction matrix by $Z(0)$ and the current-year transaction matrix by $Z(1)$, for the n sectors in the economy, the RAS technique generates the update from $3n$ pieces of information for the more recent year:

(i) Total gross output x_j;

(ii) Total interindustry (intermediate) sales, by sector $u_i = \sum_{j=1}^{n} z_{ij}$, which is the same as total output of sector i less sector $i's$ sales to final demand (since $x_i = \sum_{j=1}^{n} z_{ij} + f_i$); and

(iii) Total interindustry purchases, by sector $v_j = \sum_{i=1}^{n} z_{ij}$, which is the same as $x_j - v_j$ (total output of sector j less total purchases by j from the payments sector – labor inputs to sector j, imported inputs to sector j, taxes paid for government services, interested paid on capital loans, rental payments for land, etc.)

Thus, the problem that the RAS procedure address is: given an $n\ x\ n$ matrix $Z(0)$ and given three n-element vectors for a more recent year – $x(1)$, $u(1)$, and $v(1)$ – estimate $Z(1)$. We denote this estimate as $\tilde{Z}(1)$, and it was carried out as described below.

$$\tilde{Z}(1) = \hat{r}Z(0)\hat{s}$$ Equation (4)
$$\hat{r} = [\hat{r}^n \dots \hat{r}^1]$$
$$\hat{s} = [\hat{s}^1 \dots \hat{s}^n]$$

$$\hat{r}^1 = [\hat{u}(1)](\hat{u}^0)^{-1}$$ Equation (5)

$$\hat{s}^1 = [\hat{v}(1)](\hat{v}^1)^{-1}$$ Equation (6)

Where:
$\tilde{Z}(1)$: estimate of $Z(1)$.
$Z(0)$: base-year transaction matrix.
$\hat{r}^1$: the first adjustment in order to meet row sum information to a better estimate of $Z(1)$.
$\hat{s}^1$: the first adjustment in order to meet column sum information to a better estimate of $Z(1)$.

Additionally, to employ this method, the sectors and regions of the original matrix were aggregated, following the method presented in Miller and Blair (2009). The original matrix was aggregated 24 economic activities and in 3 regions, being 2 Brazilian watersheds select by ANA and the RBR, and.

The former was needed because part of the $3n$ pieces of information for the more recent year were obtained from national IOM with 68 sectors. So, the 24 sectors were the greatest sector detail possible in combination between these 68 sectors and 50 sectors of original matrix. The latter was chosen selected by ANA.

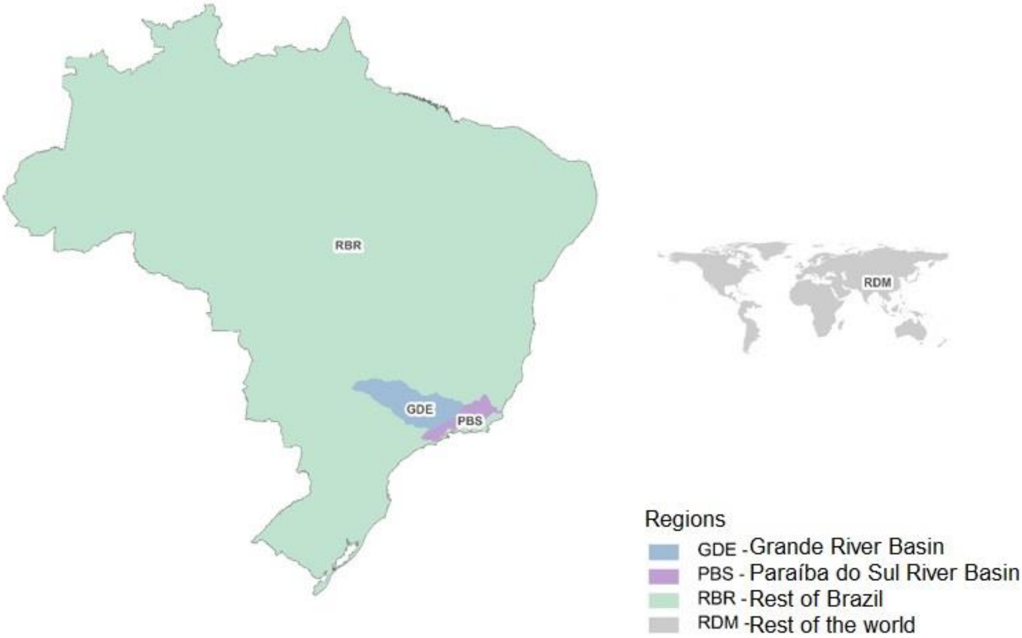
The year 2017 was chosen because it refers to the most recent year for which there was a national IOM estimated when this paper was been written, and the matrix sectors and regions are presented in table 1 and figure 1.

Table 1 – Matrix sectors

1	Agriculture, including agricultural and post-harvest support
2	Livestock, including support for livestock farming
3	Forestry production, fishing and aquaculture
4	Extractive industry, except oil and gas extraction and supporting activities
5	Oil and gas extraction, including support activities
6	Food, beverage and tobacco product manufacturing
7	Sugar manufacturing and refining
8	Textiles, clothing and accessories
9	Manufacture of shoes and leather goods
10	Wood products (excluding furniture), manufacture of cellulose, mechanical pulp, paper, cardboard, newspapers, magazines and records
11	Oil refining and coke plants
12	Biofuel manufacturing
13	Chemical elements, various chemicals, cleaning products, cosmetics, perfumery, personal hygiene, pharmochemical and pharmaceutical products, rubber and plastic products
14	Steel industry, non-ferrous metallurgists
15	Electrical material and electronic equipment
16	Manufacture of machines and mechanical equipment
17	Cars, trucks, buses, parts and other vehicles
18	Furniture and miscellaneous industry
19	Electricity, natural gas and other utilities
20	Water, sewage and waste management
21	Construction
22	Wholesale and retail trade
23	Transport
24	Other services

Source: authors.

Figure 1 – Matrix regions



Source: authors.

The $3n$ pieces of information for year 2017 were estimated by municipalities and then aggregated by the two watersheds. This aggregation was based on river basin's municipal composition. For this, the shapefiles of Brazilian municipalities and river basins, made available by ANA, were combined. To define which municipalities make up the basins, it was assumed that the basins are made up of the municipalities whose headquarters are within the basin. The information of RBR was estimated by difference between national and river basin's data. In turn, the municipal estimates were accomplished according to the following:

(i) $x(1)$: the national gross output by sector is from national Input-Output Matrix (IOM) for year 2017 made available by the University of São Paulo Regional and Urban Economics Lab (NEREUS)[11], which was estimated according to Guilhoto and Sesso Filho (2010), and Guilhoto and Sesso Filho (2005), and was disaggregated by municipality using information from the following sources:
   a. Agriculture: IBGE Municipal Agricultural Survey (PAM).
   b. Livestock: IBGE Municipal Livestock Survey (PPM).
   c. Forestry, fishing and aquaculture: PAM and PPM.
   d. Industries: Annual Social Information List (RAIS) of the Special Secretariat for Social Security and Labor of the Brazilian Ministry of Economy.
   e. Services: RAIS.

   This process ensured the consistency with the Brazilian Institute of Geography and Statistics (IBGE)'s System of Regional Accounts (SCR).

(ii) To obtain the $u(1)$, it was first estimated the final demand $f(1)$, according to the methods and sources described below.

$$y = export + hc + isfl + gfcf + g + vi \qquad \text{Equation (7)}$$

Where:

[11] http://www.usp.br/nereus/

a. $export$: column vector of exports. it was estimated by the multiplication between product export proportions for each municipality, obtained by ComexStat[12], and the export values, obtained by the national IOM of year 2017. For products whose data is not available in ComexStat, like services, the relationship used by Többen and Kronenberg (2015) and shown below was used.

$$e_p^r = e_p^{BR} * \left({x_p^r}/{x_p^{BR}} \right) \quad \text{Equation (8)}$$

Where:
e_p^r: exports of product p and region r.
e_p^{BR}: exports of product p and Brazil BR.
x_p^r: gross output of product p and region r.
x_p^{BR}: gross output product p and Brazil BR.

b. hc: column vector of household consumption. It was estimated by the multiplication between household consumption at a national level, present in national IOM of year 2017 and the share of each municipality in household consumption of each product reported in the IBGE Family Budget Survey (POF).
c. $isfl$: column vector of consumption by non-profit institutions. It was estimated by the multiplication between (i) the average between the participation of each municipality in the gross output of the sectors "Art, culture, sport and recreation and other service activities" and "Association organizations and other personal services" and (ii) the National Consumption of $isfl$, obtained in national IOM of year 2017.
d. $gfcf$: column vector of gross fixed capital formation. It was estimated by the multiplication between: (i) the average among the participation of municipalities in the national gross output of "Civil Construction" and in the national Gross Operating Surplus (eob), and (ii) the national $gfcf$. Then, the total $gfcf$ is distributed among the economic activities of the municipalities using the eob vector structure of the respective municipality.
e. g: column vector of government spending.it was estimated based on the participation of each municipality in the gross output of Public Administration sector, published by IBGE in the SCR (IBGE, 2020a and 2020b). In turn, this participation is applied to the value of national government spending, available in the national IOM of year 2017
f. vi: column vector of variation in inventories. This estimate was obtained per residue.

Finally, the $u(1)$ by municipalities was estimated by the difference between gross output $x(1)$ and final demand $f(1)$.

(iii) $v(1)$: it was estimated by equations 9 and 10.

[12] This system publishes Brazilian export and import statistics and is based on the Integrated Foreign Trade System (SISCOMEX), linked to the Ministry of Industry, Foreign Trade and Services (MDIC). It is also responsible for the administration of Brazilian foreign trade. This database is free and can be accessed via the website http://comexstat.mdic.gov.br/pt/home.

$v(1) = x(1) - imports(1) - taxes(1) - VAB(1)$ Equation (9)

$VAB(1) = wages(1) + CSEI(1) + T(1) + OT(1) + EOB(1) + RMB(1)$ Equation (10)

Where:
$Taxes_j^r$: Net Indirect Taxes (IIL).
VAB_j^r: Gross Value Added.
$Wages_j^r$: wages.
$CSEI_j^r$: Effective and Imputed Social Contributions.
T_j^r: taxes, net of subsidies, on products.
OT_j^r: other taxes, net of subsidies, on production.
EOB_j^r: Gross Operating Surplus.
RMB_j^r: Gross Mixed Income.

a. $imports\ (1)$**:** the imports were obtained by multiplication between the national imports and the share of each municipality in national imports, which was obtained through ComexStat.
b. $taxes\ (1)$**:** the IIL – such as Import Tax, Tax on Industrialized Products (IPI), Tax on Circulation of Goods and Services (ICMS) and other taxes less subsidies – was obtained from Federal Revenue, National Treasury, Social Security, Caixa Econômica Federal, Accounting Data of Municipalities (FINBRA) and National Petroleum Agency (ANP) (Royalties).
c. $VAB(1)$: The IBGE disposes the municipal VAB by four major economic activity: (i) Agriculture; (ii) Industry; (iii) Administration, defense, education, public health and social security; and (iv) other services. So, the sector disaggregation followed the method described below:
    i. $wages(1)$: the wages were obtained by multiplication between the national wages and the share of each municipality in the national wages, obtained in the Annual Social Information List (RAIS) and in Continuous National Household Sample Survey (PNAD) of IBGE.
    ii. $CSEI(1)$: the Effective and Imputed Social Contributions was employed the same structure of the national Use Matrix for year 2017. The adjustment was by the RAS method.
    iii. $T(1)$ and $OT(1)$: the Taxes, Net of Subsidies, on Products and Other Taxes, Net of Subsidies, on Production were obtained for each municipality from Federal Revenue, National Treasury, Social Security, Caixa Econômica Federal, FINBRA and ANP (Royalties).
    iv. $EOB(1)$: the Gross Operating Surplus was employed the same structure of the national Use Matrix for year 2017. The adjustment was by the RAS method.
    v. $RMB(1)$: the Gross Mixed Income was obtained by PNAD (IBGE).

By obtaining the interregional Z matrix for three regions, 24 sectors and for the year 2017, the input-output model was estimated using equations 3, 2 and 1.

Environmentally Extended Input-Output Matrix

This model was combined with detailed information from SEEA-Water of Brazil (IBGE and ANA, 2020) and from Manual of Consumptive Uses of Water in Brazil, published by ANA in 2019 (ANA, 2019b). Such information concerns the direct capture of Blue Water for consumptive uses by municipality and economic activities for the year 2017.

In the present work, the Water Footprint was estimated using the volume of Blue Water abstracted, without considering international imports of Virtual Water. This is because there are numerous variations of Water Footprint measurements, so their accounting will depend on the desired objective.

According to Hoekstra et al. (2011), River Basin managers are mainly interested in the Water Footprint referring to the water coming from the Basins under their management. That is, they are interested in the use of water from their region (in order to identify the main direct and indirect users, as well as the main demanders of products that are intensive in their water resources) and not so much in water resources from other regions.

Therefore, whenever the Water Footprint is mentioned in this report, it refers to the Water Footprint referring to the water coming from the regions studied (Paraíba do Sul River Basin, Grande River Basin and Rest of Brazil), which was estimated based on Feng et al. (2011), as described below.

$$WF_{total} = WF_{int} + WF_{ext} \quad \text{Equation (11)}$$

$$WF_{int} = WF_{db} - Exp_{av} \quad \text{Equation (12)}$$

$$WF_{db} = WF_{int} + Exp_{av} \quad \text{Equation (13)}$$

Where:

WF_{total}: Total Blue Water Footprint of a region. Refers to the volume of Virtual Water embedded in goods and services consumed in that region.

WF_{int}: Internal Blue Water Footprint of a region. It is equal to the volume of Virtual Water contained in the goods and services produced and consumed in that region.

WF_{db}: Blue Water Footprint Within a region. Refers to the volume of Virtual Water embedded in domestic production in the region.

WF_{ext}: External Blue Water Footprint of a region. Refers to the volume of Virtual Water contained in goods and services imported from other regions, whether these are interregional or international imports[13];

Exp_{av}: Virtual Water Export from a region. It concerns the volume of Virtual Water contained in exports of goods and services from that region, whether these exports are interregional or international.

Below is a diagram (table 2) on the composition of direct water abstraction in terms of Internal and External Water Footprint and the composition of the Total Water Footprint of the regions studied. The cells highlighted in gray refer to the Internal Water Footprint of each region and the others refer to the External Water Footprints, so that the sum of the External Water Footprints in each line refers to the Virtual Water exports of the region of origin.

[13] However, as already mentioned, the international import of Virtual Water was not considered.

Table 2 - Water Footprint composition

	Grande	Paraíba do Sul	Rest of Brazil	Rest of the world	Direct water abstraction
Grande	$\mathbf{WF_{int}^{G}}$	$\mathbf{WF_{ext}^{G>PB}}$	$\mathbf{WF_{ext}^{G>RBR}}$	$\mathbf{WF_{ext}^{G>RM}}$	**Total=direct water abstraction**$\mathbf{^{G}}$
Paraíba do Sul	$\mathbf{WF_{ext}^{PB>G}}$	$\mathbf{WF_{int}^{PB}}$	$\mathbf{WF_{ext}^{PB>RBR}}$	$\mathbf{WF_{ext}^{PB>RM}}$	**Total=direct water abstraction**$\mathbf{^{PB}}$
Rest of Brazil	$\mathbf{WF_{ext}^{RBR>G}}$	$\mathbf{WF_{ext}^{RBR>PB}}$	$\mathbf{WF_{int}^{RBR}}$	$\mathbf{WF_{ext}^{RBR>RM}}$	**Total=direct water abstraction**$\mathbf{^{RBR}}$
Rest of the world	$WF_{ext}^{RM>G}$	$WF_{ext}^{RM>PB}$	$WF_{ext}^{RM>RBR}$	WF_{int}^{RM}	Total=direct water abstraction^{RM}
Water Footprint	$\mathbf{WF_{total}^{G}}$	$\mathbf{WF_{total}^{PB}}$	$\mathbf{WF_{total}^{RBR}}$	WF_{total}^{RM}	

Source: authors.

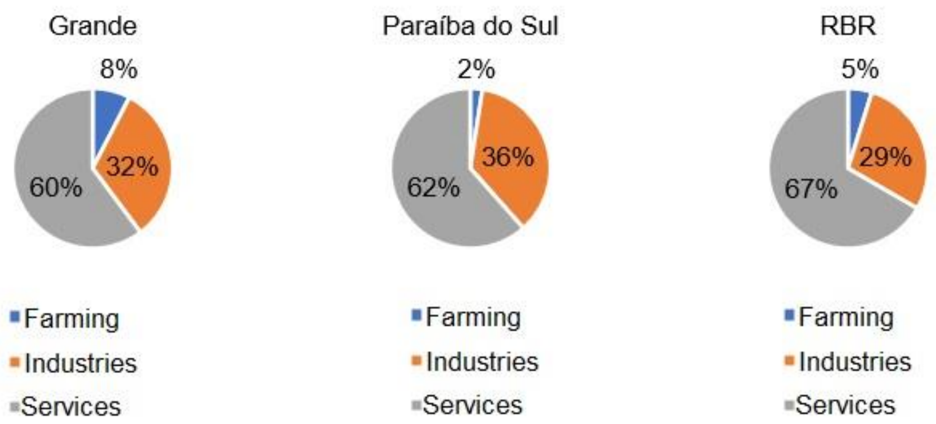
RESULTS

Region's economy

In 2017, the Value Added of the Brazilian economy was R$5.7 trillion. According to the results, the Rest of Brazil was responsible for 92% of this amount, followed by the Grande River Basin (5%) and the Paraíba do Sul River Basin (3%). Therefore, it was verified that the hydrographic basins accounted for about 8% of the national economy.

In the three regions, the most important activities for the VBP, which totaled R$11 trillion, were the services sector (63% average), followed by industry (32% average) and agriculture (5%).

Graph 1 - Sectoral breakdown of regional VBP in 2017



Source: authors.

Despite the three regions having a similar economic structure, it is important to highlight that the participation of industry in the economy of Paraíba do Sul (36%) was greater when compared to the Grande River Basin (32%) and the Rest of Brazil (29%).

At the same time, the participation of agriculture in the economy of Grande River Basin (8%) was greater when compared to Paraíba do Sul River Basin (2%) and the Rest of Brazil (5%). Therefore, it can be said that the Paraíba do Sul River Basin is more industrial and the Grande Basin is more agricultural.

Regarding the composition of the three major sectors (agriculture, industry and services), the economic structure of the regions was similar in terms of service activities and agricultural activities.

However, the industry of each region was different. While in the rest of Brazil the sector is, in a way, pulverized, in Grande River Basin and, mainly, in Paraíba do Sul River Basin, more than 50% of industrial production was concentrated in a few activities.

Furthermore, a different composition was verified for each Basin. While industrial activity in the Grande River Basin was concentrated in activities such as Food, beverages and manufacture of tobacco products (8.5%) and Sugar manufacturing and refining (4.5%), in the Paraíba do Sul River Basin 10.3 % of industrial activity was concentrated in Automobiles, trucks, buses, parts and other vehicles.

Most of the production in the regions studied was destined for Final Demand. Regarding the composition of the Final Demand, it was verified that exports from Paraíba do Sul River Basin played an important role, being responsible for about 16% of the Final Demand of the Basin, while the average between the three regions was 12%.

Regarding the composition of exports, it was found that in 2017 exports from the Rest of Brazil were scattered among different economic activities. In the Paraíba do Sul River Basin, more than half of exports were from the Automobiles, trucks, buses, parts and other vehicles sector (65%), followed by Steel, non-ferrous metallurgy (15%).

At the same time, the export basket of the Grande River Basin was concentrated in the agricultural sector (33%), with emphasis on Sugar manufacturing and refining (28%) and Food, beverages and manufacture of tobacco products (15%).

Regarding the trade flow between regions, it was found that a relevant part of the Basins production is destined for consumption in other regions (average of 46%), whether they are other regions within Brazil or other countries (this estimate for the RBR was 11%).

It is noteworthy that the production of the Hydrographic Basins intended for consumption outside the Basins themselves is mainly aimed at other regions within Brazil, rather than international exports, indicating a great economic interdependence (table 3).

Table 3 - Trade flows between regions, 2017 (BRL million)

	Grande	Paraíba do Sul	Rest of Brazil	Rest of the world	Total
Grande	294.568	5.346	182.367	26.378	508.659
Paraíba do Sul	5.648	174.216	138.326	35.127	353.317
Rest of Brazil	176.405	130.632	9.086.311	762.929	10.156.277
Rest of the world	32.309	26.856	717.972		777.137

Source: authors.

Regarding these results, two exceptions were found. In the Paraíba do Sul River Basin, most of the production – intended for consumption outside the Basin – from the sectors of (i) Automobiles, trucks, buses, parts and other vehicles; and (ii) Manufacture of machinery and mechanical equipment, were destined for international export in 2017 (61% and 60%, respectively).

In this context, it is important to note that the Rio Grande River Basin and the Paraíba do Sul River Basin exported a significant percentage of their production to the Rest of Brazil (36% and 39%, respectively).

Regarding international exports, in the Grande River Basin 5% of production was destined for international exports and in the Paraíba do Sul River Basin this result was 10%.

Additionally, it was verified that 1% of the production of Grande River Basin was destined for export to the Paraíba do Sul River Basin and 2% of the production of the Paraíba do Sul River Basin was destined for export to the Grande River Basin. That is, the most relevant interregional exports for the Basins are the trade flows for the Rest of Brazil.

Therefore, it appears that there is a great economic interdependence between the regions, indicating that a change in the economy can generate a relevant impact on the production of a given Basin and, therefore, on the use of its water resources.

Water Intensity

According to ANA (2019a), the demand for Blue Water for consumption purposes in 2017 was 65,887 hm³ or, analogously, 2,083 cubic meters per second (m³/s).

Based on the information produced in SEEA-Water of Brazil and by ANA (2019b), it was possible to estimate the portion of water abstraction that took place in the regions considered in the model. The results showed that the Grande River Basin and Paraíba do Sul River Basin were responsible for 5% and 2%, respectively, while the Rest of Brazil was responsible for 93%.

In the three regions studied, the main activities that collected water were Agriculture and Water, sewage and waste management, following the national standard shown in ANA (2019a). However, it is observed that while in the Grande River Basin and in the rest of Brazil the largest portion of the abstraction was due to agricultural activity, in Paraíba do Sul River Basin the main activity was related to Water, sewage and waste management.

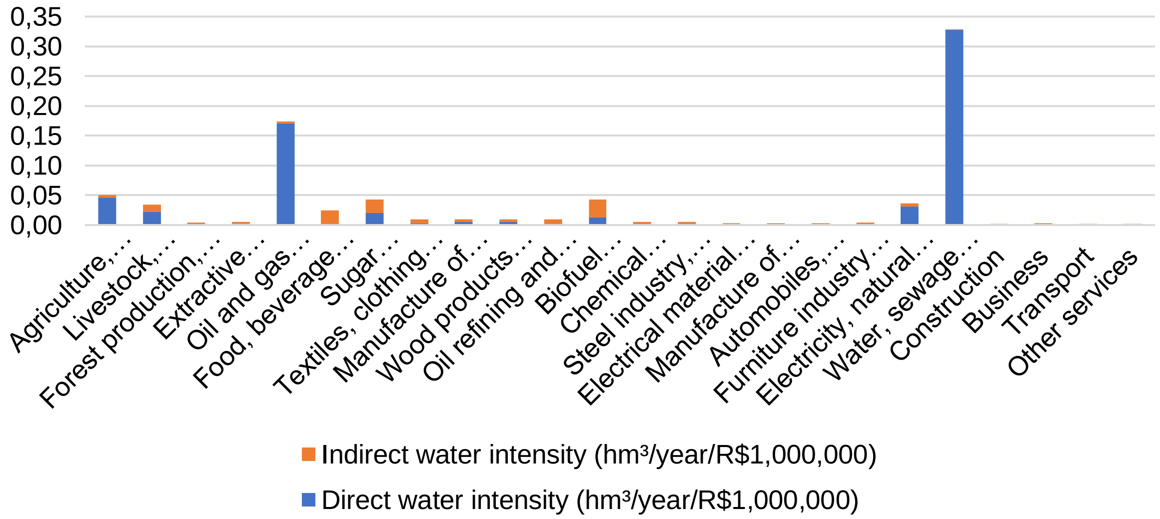
From the combination of physical and monetary information (division between the volume of water abstracted and the gross output), the direct water intensity was estimated - the volume of water abstracted (in hm³) necessary to produce one million Reais in 2017 - of the activities economies of each region studied.

Through the application of these results in the Input-Output model, it was possible to estimate the indirect water intensity. That is, the amount of water embedded in the inputs used by a given economic activity. Thus, the total water intensity was obtained, the sum of direct and indirect water intensity.

Comparing the direct and indirect water intensities, it is possible to verify the importance of water embedded in the inputs used by a given economic activity in relation to the direct use of water by this same sector.

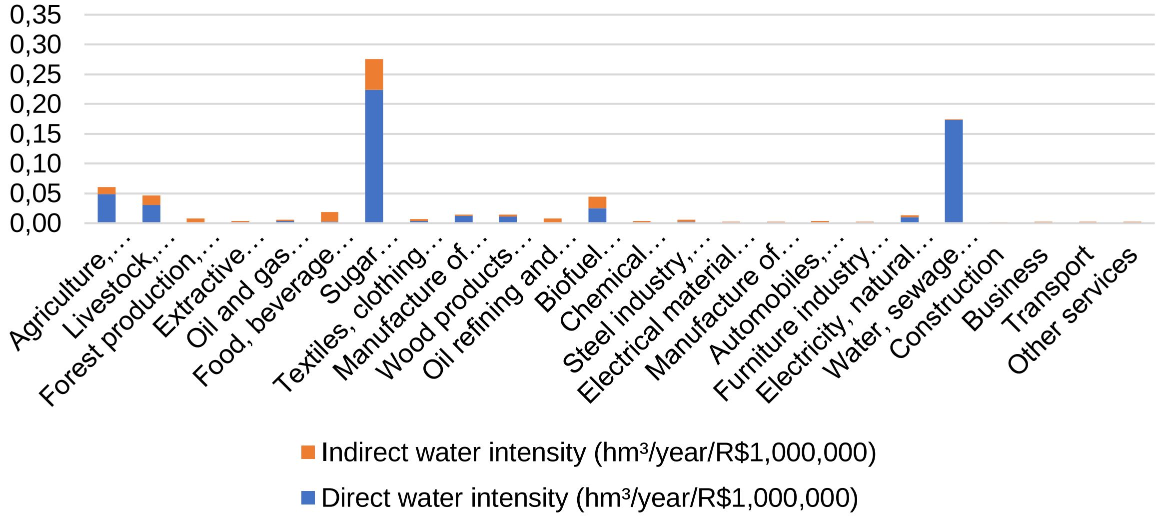
In the Grande and Paraíba do Sul River Basins (graphs 2 and 3), the most water-intensive activities are more intensive in the direct use of water. However, it is important to note that for many sectors indirect water use corresponds to a larger share than direct use.

Graph 2 - Total water intensity of economic activities in the Rio Grande Basin: 2017



Source: authors.

Graph 3 - Total water intensity of economic activities in the Paraíba do Sul River Basin: 2017



Source: authors.

In this context, it is important to point out that in both Basins the activities Biofuel manufacturing, Food, beverages and tobacco products, Sugar manufacturing and refining and Livestock presented a relevant indirect water intensity when compared to the respective direct water intensities. That is, a relevant portion of its total water use refers to the water embedded in the inputs used.

The similarity between these results indicates a similar pattern regarding the direct and indirect use of water by the same economic activities but located in different regions.

Virtual Water Flows and Water Footprint

Additionally, it is important to highlight that the place of origin of the water used indirectly can be different depending on the region studied. That is, unlike the direct water use, which generally takes place in the same Basin where the water resource was abstracted, the indirect use of water may refer to a source of water from another region.

According to table 4, the Rest of Brazil was the main water user, presenting a Water Footprint of around 43,104 hm³ in 2017. In second place was the Rest of the World, whose Water Footprint was 18,916 hm³. Next, the Grande River Basin (1,777 hm³) and the Paraíba do Sul River Basin (1,126 hm³) stood out.

Table 4 - Virtual Water Flows and Water Footprint (hm³): 2017

	Grande	Paraíba do Sul	Rest of Brazil	Rest of the world	Direct water abstraction
Grande	596	44	1.445	875	2.960
Paraíba do Sul	23	263	600	140	1.027
Rest of Brazil	1.158	818	41.060	17.901	60.937
Rest of the world	-	-	-	-	-
Water Footprint	1.777	1.126	43.104	18.916	64.924

Source: authors.

In this context, it is interesting to observe the Water Footprint composition. The estimates presented in table 5 indicate that 65% of the Grande River Basin's Water Footprint refers to the External Water Footprint coming from the Rest of Brazil. That is, to interregional exports of Virtual Water from the Rest of Brazil to the Grande River Basin.

Additionally, it is observed that 34% of the Grande River Basin's Total Water Footprint refers to the Internal Water Footprint and only 1% refers to the External Water Footprint, related to the Virtual Water flows originating in the Paraíba do Sul River Basin.

In turn, 73% of the Paraíba do Sul River Basin's Total Water Footprint was embedded in goods consumed in the Basin and produced in the Rest of Brazil (External Water Footprint related to Virtual Water flows originating in the Rest of Brazil). About 4% referred to the External Water Footprint coming from the Grande River Basin and 23% referred to the Internal Water Footprint, that is, the water embedded in the products consumed and produced in the Paraíba do Sul River Basin itself. That is, the Paraíba do Sul River Basin is more dependent on water from the Rest of Brazil than the water from the Grande River Basin and from the Paraíba do Sul River Basin itself.

The Water Footprint of the Rest of Brazil concerned mainly the Internal Water Footprint, that is, the water embedded in products consumed and produced in the region itself (95%). Around 4% referred to the External Water Footprint, coming from the Grande River Basin (3%) and the Paraíba do Sul River Basin (1%). Similar results are observed for the Rest of the World.

Table 5 - Virtual Water Flows and Water Footprint (%): 2017

	Grande	Paraíba do Sul	Rest of Brazil	Rest of the world
Grande	34%	4%	3%	5%
Paraíba do Sul	1%	23%	1%	1%
Rest of Brazil	65,10%	72,70%	95%	95%
Rest of the world	-	-	-	-
Water Footprint	100%	100%	100%	100%

Source: authors.

The difference in Virtual Water flows and the water abstracted composition reflects the different size, structure and insertion of the economy in interregional and international trade, as well as its patterns of water intensity.

The results showed that the main Virtual Water flows from the Grande River Basin to the Rest of Brazil were related to water embedded in Agricultural products, accounting for 39% of this result, followed by Water, sewage and waste management (21%), Sugar manufacturing and refining (14%) and Livestock (9%).

It is important to highlight that this structure remained the same about the Virtual Water flows from the Grande River Basin to the Paraíba do Sul River Basin, changing only the percentages (40%, 17%, 16% and 9%, respectively).

Similarly, it was found that the main Virtual Water flows from the Grande River Basin to international exports concerned water embedded in goods produced by Agricultural activity, with 61% of international exports of Virtual Water coming from this activity and 23% of Sugar manufacturing and refining.

The main Virtual Water flows from the Paraíba do Sul River Basin to the Rest of Brazil were related to water used in the activity of Water, sewage and waste management, since 41% of the export of Virtual Water to the Rest of Brazil came from this activity. Then, it was verified that 26% related to the Agriculture activity and 10% to Livestock.

This structure remained the same regarding Virtual Water flows from the Paraíba do Sul River Basin to the Grande River Basin, changing only the percentages (45%, 27%, and 9%, respectively).

Similarly, it was found that the main Virtual Water flows from the Paraíba do Sul River Basin for international exports concerned water embedded in the activity Water, sewage and waste management, with 31% of international export of Virtual Water came from this activity, 22% was from Sugar manufacturing and refining, 18% from Steel, non-ferrous metallurgists, 12% from Wood products (excluding furniture), manufacture of cellulose, mechanical pulp, paper, cardboard, newspapers, magazines and discs and 5% from Livestock.

The important result verified for the Water, sewage and waste management sector is due to the fact that the water collected and distributed by this sector is an important production input for the activity of Automobiles, trucks, buses, parts and other vehicles. As the latter is relevant for the Basin's trade – being responsible for 21% of the interregional exports of the Paraíba do Sul River Basin and for 65% of the international exports of the same Basin in 2017 – this implied interregional and international exports of Virtual Water.

Trade and Virtual Water Balance

Comparing trade and Virtual Water flows, the Grande River Basin was in deficit in the Trade Balance (table 6) but surplus in Virtual Water flows (table 7). Therefore, these results indicate that this region exports proportionally more in terms of Virtual Water than in monetary terms.

This was due to the importance of agriculture for the interregional and international exports of the Basin, which concerns an activity with high water intensity.

On the other hand, the Paraíba do Sul River Basin has a surplus in the Trade Balance (table 5), but a deficit in Virtual Water flows (table 6), which indicates that it exports proportionally less in terms of Virtual Water than in terms of monetary.

This result is related to the fact that most of the interregional and international exports of this Basin referred to the exports of industrial activity, which is less water intensive when compared to agricultural activities.

Table 6 - Trade balance (R$ million) in 2017

	Interregional and international supply	Interregional and international demand	Trade balance
Grande	214.091	214.362	-271
Paraíba do Sul	179.101	162.834	16.267
Rest of Brazil	1.069.966	1.038.665	31.301
Rest of the world	777.137	824.434	-47.297

Source: authors.

Table 7 - Virtual Water balance (hm^3) [1] in 2017

	Supply	Demand	Virtual Water balance
Grande	2.364	1.181	1.183
Paraíba do Sul	764	862	-99
Rest of Brazil	19.877	2.044	17.833
Rest of the world	-	-	-

[1] International exports of Virtual Water from Brazil in 2017 were 18,917 hm^3. As mentioned throughout the text, Virtual Water imports from Brazil were not estimated in this study. However, the literature points out that Brazil is a net exporter of Virtual Water. That is, it exports more in terms of Virtual Water than it imports (Hoekstra & Mekonnen, 2012).
Source: authors.

In summary, the monetary and physical results showed that the main activities from the water use, and Virtual Water flows points of view may not be the main activities in economics and trade flows terms.

Impact of Virtual Water flows on Sustainable Water Use

In regions with water restrictions, it may be even more important to know not only the main direct water users, but also the main indirect users.

In these cases, it is even more important to identify whether these uses are to produce goods and services that are important in generating value and employment for the local economy.

To explore these results, it was initially identified how the quantitative Water Balance of the studied regions can be classified.

ANA (2019a) estimates the relationship between water use and availability, the so-called quantitative Water Balance, or Water Exploitation Index (IEA), classified as follow:

- < 5% - Excellent. Little or no management activity is required. Water is considered a free good.
- 5 to 10% - The situation is comfortable, and there may be a need for management to solve local supply problems.
- 10 to 20% - Worrying. The management activity is essential, requiring medium investments.
- 20% to 40% - The situation is critical, requiring intense management activity and large investments.
- 40% - The situation is very critical.

According to Alcamo, Henrichs and Rosch (2000), this means that the use of water downstream of locations where this index occurs may be harmed. There may be more chances of absolute water scarcity occurring in some parts of these regions during periods of low water flows. Thus, in addition to the consequent interruption of water abstraction, water flows in nearby regions may be insufficient to sustain local aquatic ecosystems (ALCAMO, HENRICHS, RÖSCH, 2000).

As can be seen in table 8, the Grande River Basin was in a worrying situation, with 12.6% of the 744.28 m³/s of water availability committed to the demand for consumptive uses (93.9 m³/s). A relevant part of this consumptive use is destined to the production of goods and services exported to other regions and/or countries (75 m³/s, or 10.1% of water availability).

The balance of the Paraíba do Sul River Basin was in a comfortable situation, with 8.9% of water availability committed to the withdrawal flow for consumptive use[14]. Analogously, the demand from outside the Basin itself is mainly responsible for the criticality classification in the Water Balance (24.2 m³/s, or 6.6% of water availability).

[14] This Balance reflects the existing demand as well as the supply of water in the Paraíba do Sul Basin. However, this Basin is responsible for supplying a large part of the Metropolitan Region of Rio de Janeiro, through the transposition to the Guandu River basin. Although this transposition was not considered in the data on water demand, it was considered in the data on water supply (availability). The fact that, even so, the Basin is being classified as “Comfortable” is related to the spatial cut. That is, the data were analyzed in terms of the Basin as a region. Certainly, if the Basin is disaggregated into sub-basins within the model, different results will be verified for the respective Water Balances.

Table 8 - Quantitative balance between availability¹ and demand 2017 (m³/s)

		Watershed	
		Grande	Paraíba do Sul
Water availability¹ - Q95 nat (m³/s)		744,28	366,3
Consumptive use (m³/s)	Total	93,9	32,6
	For goods and services from the Basin itself	18,9	8,4
	For goods and services from outside the Basin	75	24,2
Withdrawal flow rate and water availability	Total	12,60%	8,90%
	For goods and services from the Basin itself	2,50%	2,30%
	For goods and services from outside the Basin	10,10%	6,60%

Source: authors.

It was also verified that the Grande River Basin's sectors with the highest consumptive use of water - Agriculture, Water, sewage and waste management and Sugar manufacturing, responsible for 80% of water abstraction in the Basin – accounted for only 10% of value added and 20% of employment in the region.

Additionally, it is important to mention that the Agriculture and Sugar Manufacturing's most of the consumptive water use is given to meet the demands of regions outside the Basin itself, with a relevant participation of international exports.

Regarding the Paraíba do Sul River Basin, it was found that the sectors with the highest consumptive water use are Water, sewage and waste management and Agriculture. For Agriculture, most of the consumptive use of water is given to meet the demands of regions outside the basin itself, and most of it is destined for the Rest of Brazil.

In this context, it is also important to highlight that water and sewage and agriculture activities were responsible for 71% of the direct collection of Blue Water in the Basin but contributed with only 3% of Value Added and Employed in the region.

In the Rest of Brazil, agriculture stands out as the sector with the highest consumptive water use, with around 40% of the water used in agriculture being destined for international exports, while contributing only 3% of Value Added and 6% of employed persons in the region.

Therefore, the results showed that, in the studied regions, the main economic activities responsible for the direct capture of Blue Water for consumptive use contribute little to the aggregation of value in the economy and to employment, indicating that this seems to be a characteristic of water intensive activities.

DISCUSSION

The use of information produced in the SEEA-Water of Brazil and ANA data in economic models has a great potential for generating relevant information to help manage water resources towards sustainable use.

Among this information, the potential derived from the comparison between the participation of economic activities and/or regions in water abstraction, value added and employment generation stands out.

The approach adopted in this article can contribute water management. It was found that by combining physical information on direct water use and the EE-IOT model, it is possible to map water use in supply chains and estimate Virtual Water flows embedded in interregional and international trade, producing information on the economic and, consequently, water interdependence between the regions.

In addition to this information being useful for estimating the Water Footprint, through said mapping it is possible to estimate the impact of the economy of a region or country on the economy of a given Hydrographic Basin and, therefore, on the use of its water and, consequently, on its water balance.

That is, with the increase in the complexity of supply chains and with the growth of economic integration of different regions and countries through trade, more and more information has been demanded, not only about the main direct users of natural resources, but also about the main indirect users, as well as consumers of goods and services that are intensive in these resources, with the aim of subsidizing the creation, improvement and application of incentive mechanisms for sustainable use.

Additionally, the association of this information with data on the generation of value added and employment can contribute to the design of mechanisms for mediating conflicts over water use, as well as to defining priority uses of water, considering local heterogeneities with relation to the structure of demand for water and water availability.

Finally, this study also contributes to the discussion on expanding the conceptual and methodological basis used in the management of water resources, bringing new possibilities for research and production of relevant information for water conservation in Brazil.

ACKNOWLEDGMENTS

The authors are grateful to National Water and Sanitation Agency (ANA) and Inter-American Institute for Cooperation on Agriculture (IICA) for supporting this research.

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