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## Article

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# Economic and water dependence among regions: The case of Alto Tiete, Sao Paulo State, Brazil

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## Abstract

To illustrate the importance of the regional scale of water uses, this paper identifies the direct and indirect water use of the Sao Paulo State Water Resources Management Units (WRMUs) and the rest of Brazil by focusing on Alto Tiete WRMU. The Alto Tiete WRMU has been suffering from water scarcity and its boundaries are similar to that of the Sao Paulo Metropolitan Region.

To this aim, a subnational interregional input–output model was estimated with a high degree of disaggregation (83 sectors and 23 regions) and a detailed estimation of water use coefficients that differ not only among sectors but also among the regions was applied. These coefficients also took into account their regions' endoclimatic characteristics.

The resulting database allows quantifying the water embedded in the goods (virtual water) traded among Alto Tiete WRMU and other regions. The results show that despite its commercial trade surplus, Alto Tiete actually presents a virtual water trade deficit, showing that it exports goods that are less intensive in water use, while importing goods that are more water intensive.

This study provides new insights and a scientific reference for public policies concerned with the management of water resources at the regional scale.

*Keywords:* Virtual water; Water footprint; Interregional input–output model; Brazil

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## 1. Introduction

World population growth associated with rising economic growth rates and the consequent improvement of the standard of life are placing a mounting pressure on the environment and are making fresh water an increasingly scarce resource.

Giving the regional location of water resources, it is crucial to measure its availability and use at the local level as well as how it crosses local regional boundaries, which can be either in form of direct transfer to other regions, or as water used to produce goods exported to other regions, *i.e.* as water embedded in these goods (virtual water).

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To illustrate the importance of the regional scale for water management when modeling, we chose a big country with a relative abundance of water (high per capita water availability), *i.e.* Brazil, and produced a detailed regional study for the Sao Paulo State, the most developed state in the country.

Sao Paulo State holds 3% of Brazil's water availability, but 21.6% of Brazil's population. Sao Paulo State presents a per capita water availability of 2666 m<sup>3</sup>/hab/year (São Paulo et al., 2013), which is considered a situation with no water scarcity according to the UN-Water category thresholds<sup>3</sup> (United Nations, 2015). However, if the scale of the analysis is changed to less than 5% of Sao Paulo State's territory, in which the Sao Paulo Metropolitan Region is included, the water resource situation would change drastically.

Coping with water scarcity in cities requires complex hydraulic structures to withdraw gross water from unstressed sources. In cases water must travel more than 94 km (McDonald et al., 2014). Big cities like Sao Paulo are connected to other regions not only by such water infrastructures, but also through the economy.

When two different regions trade goods they are also trading the water used to produce these goods, or water 'embedded' in these goods, the virtual water. This concept was first used by Allan in 1993 to describe the total volume of water embedded in agriculture products, suggesting that water scarce regions should import water intensive products. It is called virtual water because it is not related to the water contained in the product, but to the water used in its production. The concept can be expanded to other goods and services (Allan and King, 2003). As pointed out by Reimer (2012), once water is recognized as a production factor, the virtual water concept can be translated as the service of water. Therefore, virtual water trade is the exchange of services of the water-factor embodied in goods, following the "very long tradition in international economics of viewing trade as the international exchange of services of factors embodied in goods" (Reimer, 2012, p. 135). More than that, this author has presented the theoretical results that place the virtual water concept on the Heckscher–Ohlin model of trade.

Quantification of virtual water in different sectors of the economy is gradually being adopted to help design public policy for water resources (Dietzenbacher and Velázquez, 2007; Zhang et al., 2011). Estimation on virtual water trade among different countries has also been conducted in order to offer a better understanding of this issue (Hoekstra and Hung, 2005; Chapagain and Hoekstra, 2008). For some large countries it has also become relevant to understand the internal virtual water trade within the country (Hoekstra and Hung, 2005; Brown et al., 2009; Mubako et al., 2013). Thus, a sectoral investment in a particular region can affect water demand in the other region, or, on the contrary, water scarcity problems in one region can affect output in another.

Despite these efforts, the use of virtual water trade data to policy prescription is declining due to the lack of empirical evidence showing that relative water abundance is a good predictor for trade flows of water-intensive products (Ansink, 2010). Reimer (2012) argues that these deviations are not caused by the weak economic theory supporting the concept, but instead by real world deviations from the assumptions of the standard trade model. Nevertheless, it is undeniable that the virtual water concept has been helpful in gaining the attention of public officials and policy makers revealing aspects related to production, consumption, and trade in goods, which monetary indicators do not capture. This in turn calls for a new governance approach to water that considers water in a wider dimension, besides that of the river basin (Antonelli and Sartori, 2015).

The economic relations shown in an interregional input–output (IRIO) model allow not only the identification of the direct water use by different economic sectors, but also the indirect use embedded in the consumption of products from other sectors. Economic-environment models based on input–output analysis are considered suitable for virtual water consumption estimates and for other indicators such as the ecological footprint and embodied emissions (Wiedmann et al., 2007). Its top-down approach accounts for the entire industrial supply chain, in contrast to the bottom-up water footprint or life-cycle approaches (Paterson et al., 2015). However, the lack of detail on agricultural products, as well as lack of spatial detail makes it difficult to provide policy recommendations and guidance for water resource management (Feng et al., 2011).

This paper analyzes how water use in different regions is linked through their economic co-dependencies. We present trade data among different Water Resources Management Units (WRMUs) inside Sao Paulo State and the virtual water

<sup>3</sup> Per capita water availability between 1700 and 2500 m<sup>3</sup>/hab/year shows vulnerability regarding water resources. This threshold may be very close to the one presented by Sao Paulo State (2666 m<sup>3</sup>/hab/year) and some readers may interpret this result as Sao Paulo being close to this vulnerability situation. Nevertheless, the study that presented Sao Paulo's index have only considered water production inside the state's territory (São Paulo et al., 2013). Adding water production from outside the state's territory but that flows into its territory to water availability may triplicate the index (São Paulo and Conselho Estadual de Recursos Hídricos, 2006).

trade among these units,<sup>4</sup> by illustrating the analysis with one particular WRMU called Alto Tiete. Alto Tiete contains the majority of the Sao Paulo Metropolitan Area.

Virtual water trade was estimated based on water withdrawal. It is one of the most important variables for water resources management in drainage basins and in Brazil, water withdrawal requires a license.<sup>5</sup> Thus, it differs from the traditional water footprint approach, which is divided into green, blue and gray water. The green component refers to rainwater, the blue component to consumption of surface water or groundwater (whereby water consumption is often smaller than water withdrawal because part of a water withdrawal returns to the ground or surface water) and the gray component refers to the volume of water required to assimilate pollutants entering freshwater bodies (Hoekstra et al., 2011). It is worth mentioning that the returned amount of water usually does not become available to other uses in the same freshwater body with the same quality as presented when it was withdrawn. For this reason, wastewater discharge is commonly not deducted from water withdrawal in some blue water footprint estimates (Hoekstra and Chapagain, 2007; Zhang et al., 2011). This distinction is more important as the geographical scale of analysis becomes smaller.

The input–output framework has already been used for this purpose in other regions, such as China (40 sectors, 7 regions) (Guan and Hubacek, 2007) and Australia (344 sectors, 8 regions) (Lenzen, 2009), but never at the detailed regional level as in this paper. A more detailed discussion concerning virtual water and input–output analysis can be found in Mubako et al. (2013).

Brazilian virtual water trade has already been estimated by some authors in the international water trade context using the bottom-up water footprint approach (Hoekstra and Hung, 2005; Chapagain and Hoekstra, 2008; Hoekstra and Mekonnen, 2012). da Silva et al. (2016) have detailed the virtual water trade among Brazilian states and other countries using the same approach, arguing that the origin of virtual water exports matters given that water resources in the country are unevenly distributed.

The novelty of this study resides in, on the one hand, showing the importance of the regional scale of water management at the water basins level and how it is traded among different regions, using Brazil as a case study, and, on the other hand, as part of conducting this study, in estimating a highly disaggregated IRIO model and water use coefficients, for 83 sectors and 23 regions, which will be made publicly available for enabling further studies.

This paper is organized as follows: the second section presents geographical and development aspects of Sao Paulo state. Section 3 presents the methodology and database used to estimate the interregional input–output model and the water withdrawal technical coefficients. Section 4 presents an analysis of the economic and water interdependencies among the regions and their trade flows; the water use is measured from producers' and consumers' perspective. Concluding remarks are made in Section 5.

## 2. Geographical and development aspects

Sao Paulo State is divided into 22 Water Resource Management Units (WRMU) based on the state's hydrography,<sup>6</sup> each with its own committee<sup>7</sup> (São Paulo and Conselho Estadual de Recursos Hídricos, 2006). The most critical regions regarding water resources are regions 6-AT (Alto Tiete) and 5-PCJ (Piracicaba/Capivari/Jundiá) (Fig. 1).

Population and GDP are concentrated in region 6-AT (Alto Tiete). With only 5868 km<sup>2</sup> (2.4% of Sao Paulo's territory), this region accounts for 47.3% of Sao Paulo State's population (Instituto Brasileiro de Geografia e Estatística, 2011a) and for 56.3% of the state's GDP (Fundação Sistema Estadual de Análise de Dados, 2010).

Water scarcity problems in this region have been on the State's agenda since the middle of the 20th century, due to the rapid urbanization of Sao Paulo city (Companhia de Saneamento Básico do Estado de São Paulo, 2008). During the 1970s, these problems led to the construction of a transboundary water infrastructure between region 5-PCJ (Piracicaba/Capivari/Jundiá) and region 6-AT with the so called Cantareira System. In this system, 33 m<sup>3</sup>/s of gross water from region 5-PCJ were pumped through Cantareira hills and were treated and distributed to people living in

<sup>4</sup> There are some 'real' water transfer between WRMUs in Sao Paulo State (see Section 2). This kind of transfer is not included in the virtual water trade analysed in this paper.

<sup>5</sup> Water is considered a public good in Brazil. Water withdrawal and effluent discharge require a license.

<sup>6</sup> These WRMU divisions are related only to water resources under state jurisdiction, namely the ones entirely within state boundaries. Water resources that cross or divide two or more states are under federal jurisdiction and are not considered in this study. For more information on the Brazilian water resources management policy, see Elabras Veiga and Magrini (2013).

<sup>7</sup> There are actually 21 committees to 22 WRMU. One of the committees manages 2 WRMUs.

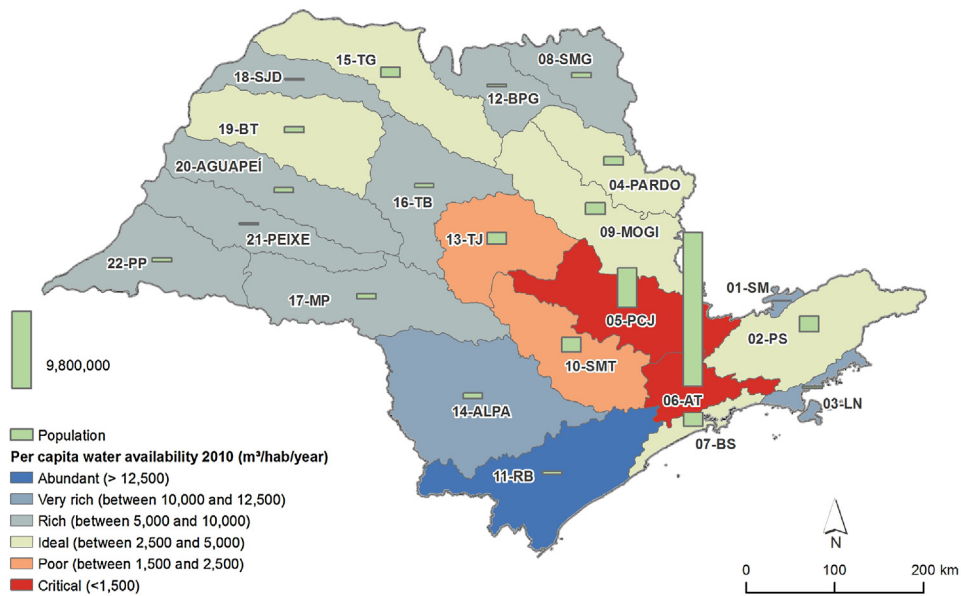


Fig. 1. Per capita water availability in Sao Paulo state WRMU's – 2010. Data source: [São Paulo et al. \(2013\)](#).

region 6-AT, which is mainly the Sao Paulo Metropolitan Area ([Agência Nacional de Águas and Departamento de Águas e Energia Elétrica, 2004](#)). Currently, this system is responsible for about half of the total amount of water that the Basic Sanitation Company of Sao Paulo State (SABESP)<sup>8</sup> provides to people living in Sao Paulo Metropolitan Area ([Ribeiro, 2011](#)). During the 1980s and 1990s, cities in the region 5-PCJ have undergone enormous industrial and urban development, which was not predicted in the water demand assessment at the time the Cantareira System project was being planned and has resulted in the critical per capita water availability observed today ([Fig. 1](#)). It has led to a water use conflict between the two basins. In 1991 the first river basin management committee (called PCJ – Piracicaba, Capivari and Jundiá) in Brazil was established. In 2004, during the first water transfer license renewal process, it was defined that the water transfer would be lowered to 31 m<sup>3</sup>/s and that several operational rules were to be applied during drought conditions ([Andrade et al., 2011](#)). Recently, the region experienced a severe drought (2014–2015) and the license was reviewed with the result that the water transfer would range between 15.5 m<sup>3</sup>/s and 33 m<sup>3</sup>/s depending on the accumulated water volume of the system ([SABESP, 2016](#)).

Another transboundary water infrastructure, called Serra do Mar project, was constructed earlier, in the 1920s and 30s, connecting regions 6-AT and 7-BS (Baixada Santista). In this system, the natural flow regime of Tiete river was inverted towards the maritime slopes of Serra do Mar hills, in order to generate hydropower at Henry Borden plant at the foot of the mountain range (157 m<sup>3</sup>/s, 750 m drop) in region 7-BS. The lack of wastewater collection and treatment in region 6-AT in the following years caused the eutrophication of Billings reservoir, which is part of the Serra do Mar project, but also an important reservoir for water supply. In 1988, the water reversal to Billings reservoir was discontinued ([Braga et al., 2006](#)) and nowadays it operates only to help control floods ([Empresa Metropolitana de Águas e Energia, 2014](#)). The water transfer between these regions was reduced to 22.5 m<sup>3</sup>/s and became limited to the part located upstream to the Billings reservoir ([São Paulo and Conselho Estadual de Recursos Hídricos, 2006](#)).

These real water transfers between different regions in Sao Paulo State illustrate the complexity of water resources management in water scarce areas.

<sup>8</sup> SABESP is the main water production and supply/sewage treatment company at Sao Paulo State. According to National System on Sanitation Information (SNIS) data, in 2009 this company was responsible for 364 (out of 645) municipalities in Sao Paulo State, and it supplied water for 56.5% of state's population. In Sao Paulo Metropolitan Area, SABESP supplies treated water for 79% of its population and 32 out of its 39 municipalities.

### 3. Methodology and data

#### 3.1. Input–output framework

The input–output model consists basically of a linear equations system which describes the production distribution among different industries in an economy. An input–output matrix represents the interindustry flows of an economy in a certain period of time (Miller and Blair, 2009). The standard interregional input–output model is presented by Eq. (1):

$$x_i^R = \sum_{S=1}^r \sum_{j=1}^n z_{ij}^{RS} + \sum_{S=1}^r y_i^{RS} \quad (1)$$

where  $n$  is the number of industries (sectors) of an economy,  $r$  is the number of regions of that economy,  $x_i^R$  is the total output of sector  $i$  in region  $R$ ,  $z_{ij}^{RS}$  is the intermediate consumption of sector  $j$  in region  $S$  supplied by sector  $i$  in region  $R$  and  $y_i^{RS}$  is the final demand of region  $S$  supplied by sector  $i$  in region  $R$ .

The technical coefficient  $a_{ij}^{RS}$  represents the intermediate consumption of sector  $j$  in region  $S$  supplied by sector  $i$  in region  $R$ . It is obtained by the ratio between the monetary flow  $z_{ij}^{RS}$  and the total output from sector  $j$  in region  $S$ ,  $x_j^S$ :

$$a_{ij}^{RS} = \frac{z_{ij}^{RS}}{x_j^S} \quad (2)$$

Substituting (2) into (1):

$$x_i^R = \sum_{S=1}^r \sum_{j=1}^n a_{ij}^{RS} x_j^S + \sum_{S=1}^r y_i^{RS} \quad (3)$$

Rewriting (3) in the matrix form:

$$X = AX + Y \quad (4)$$

$$X = [x_i^R], \quad A = [a_{ij}^{RS}], \quad Y = [y_i^{RS}]$$

where  $X$ ,  $A$  and  $Y$  are output, technical coefficients and final consumption matrices, respectively.

Solving (4), results in the total output requirement to the final demand:

$$X = (I - A)^{-1}Y \quad (5)$$

where  $(I - A)^{-1} = B = [b_{ij}^{RS}]$  is a  $(nr \times nr)$  matrix which contains the direct and indirect coefficients of production, in which each element  $b_{ij}^{RS}$  indicates the total output from sector  $i$  in region  $R$  that is necessary to produce a unit of final demand from sector  $j$  in region  $S$ . This matrix is also called the Leontief inverse matrix.<sup>9</sup>

From matrix  $B$ , one can estimate the output multiplier<sup>10</sup>:

$$OM_j^S = \sum_{R=1}^r \sum_{i=1}^n b_{ij}^{RS} \quad (6)$$

The output multiplier  $OM_j^S$  indicates the direct and indirect effects of a sector  $j$  in region  $S$  given the increase in one monetary unit of final demand of this sector in this region.

<sup>9</sup> Households are not endogenous in this model.

<sup>10</sup> Type I output multiplier. See Miller and Blair (2009).

The link between water use and monetary flow is done through the direct water use coefficient. It is defined as the amount of water required to produce one unit of total output. This coefficient represents the intensity of direct water use and it is expressed as

$$c_j^S = \frac{w_j^S}{x_j^S} \quad (7)$$

where  $c_j^S$  is direct water use coefficient from sector  $j$  in region  $S$ , measured in  $\text{m}^3/10^6$  USD in this study, and  $w_j^S$  (in  $\text{m}^3$ ) and  $x_j^S$  (in monetary terms) are water resources use and total output value from the same sector and region, respectively.

One can use different concepts for water use  $w$  when calculating coefficient  $c$ , depending on the objective of the study. In the present one, we have used water withdrawal ( $Q_w$ ).

Total water use coefficients  $g_{ij}^{RS}$  represents the direct and indirect water use impact in sector  $i$  from region  $R$  caused by one monetary unit of final demand for sector  $j$  from region  $S$ . It is obtained as follows:

$$g_{ij}^{RS} = c_i^R b_{ij}^{RS} \quad (8)$$

Thus  $g_{ij}^{RS}$  obtained from water withdrawal ( $Q_w$ ), measured in  $\text{m}^3/10^6$  USD in this study, is the quantity of gross water in sector  $i$  from region  $R$  required to supply, directly and indirectly through inputs to other sectors and regions, to meet one monetary final consumption of sector  $j$  from region  $S$ .

Total water use,  $wu_i^{RS}$ , represents the volume of water (in  $\text{m}^3$ ) required to supply for the final demand of one region, directly through the water embedded in the final demand itself, but also indirectly through the water embedded in the inputs sold to other sectors of the economy to meet this final demand. It is obtained by:

$$wu_i^{RS} = \sum_{T=1}^r \sum_{k=1}^n g_{ik}^{RT} y_k^{TS} \quad (9)$$

where  $wu_i^{RS}$  is the direct and indirect water resources use from sector  $i$  at region  $R$  caused by final demand from region  $S$ .

Total water use flows among regions  $R$  and  $S$  is:

$$wu^{RS} = \sum_{i=1}^n wu_i^{RS} \quad (10)$$

From the producer's perspective, total water use of region  $R$  is:

$$wu^R = \sum_{S=1}^r wu^{RS} \quad (11)$$

where  $wu^R$  represents the total water use in region  $R$  to supply goods and services to all regions.

Finally, from the consumer's perspective, total water use of region  $S$  is:

$$wu^S = \sum_{R=1}^r wu^{RS} \quad (12)$$

where  $wu^S$  represents the total water use from all regions in order to supply goods and services to region  $S$ .

### 3.2. Interregional input–output model

The process to estimate the interregional input–output model used in this paper can be summarized in the following steps: (a) by applying the methodology presented in [Guilhoto and Sesso-Filho \(2005\)](#) and [Guilhoto and Sesso-Filho \(2010\)](#) the input–output matrices for the Brazilian economy based on the Brazilian System of National Accounts (year 2009) released by the Brazilian Statistical Office (IBGE) was estimated; (b) based on information derived from the IBGE databases as well as from other sources, the number of sectors and products from the estimated national input–output matrices was expanded; (c) from the expanded national system and by applying the methodology presented in [Guilhoto et al. \(2017\)](#) the interstate I-O system for the twenty-seven states of Brazil (including the Federal District)

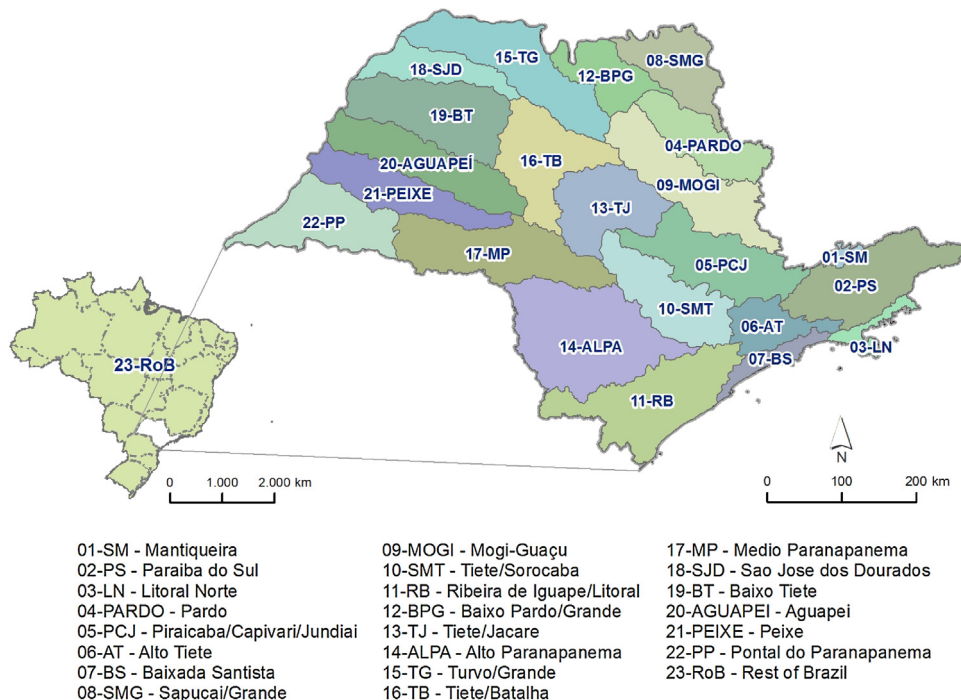


Fig. 2. Interregional input–output matrix with 23 regions.

was estimated; and (d) subsequently, based on the interstate I-O system, the state of Sao Paulo was broken down into smaller regions by a process of extraction, tabulation and processing of municipal information; different methodologies are used in this procedure and an overview of this process is presented in [Ichihara et al. \(2013\)](#). This data allowed the matrix disaggregation to the municipal level, which was afterwards aggregated to the 23 regions presented in [Fig. 2](#). Municipalities with territories across two or more regions were allocated to the region that contains its urban area.<sup>11</sup>

The matrix was conceived with 83 economic sectors (see Appendix 1), so that agriculture, livestock and industry sectors were kept in the highest feasible level of disaggregation. On the other hand, the service sectors were highly aggregated once water use is not considered as an essential part of its production process.<sup>12</sup>

All monetary values were converted from Brazilian Real to US Dollar using the 2009 average exchange rate (1 USD = 1.9931 BRL) ([Banco Central do Brasil, 2016](#)).

### 3.3. Water withdrawal technical coefficients

The water withdrawal technical coefficients ( $c_j$ , in  $m^3$  of water/ million USD) were estimated differently for each group of sectors and focused on the water intensive sectors.

Estimating water withdrawal, consumption and return of one region has been one of the challenges of water management master plans. A variety of methodologies can be found in the literature and a combination of them was employed in this study to estimate water use for the main water consumption sectors.

<sup>11</sup> 215 out of 645 municipalities from Sao Paulo State were allocated in one WRMU using this criteria. On one side, manufacturing industries and services are concentrated in urban areas. On the other side, agriculture and mining sectors, which are commonly water intensive sectors, are distributed in rural areas. However, we believe that any simplification that may have been introduced by this criteria is attenuated by the randomness of urban area location between two or more WRMUs.

<sup>12</sup> The water consumed by workers and families is accounted through the water supply sector.



The industry and agriculture sectors' estimates are based on [Fundação Banco do Brasil et al. \(2011\)](#). For the industry sectors we used the water withdrawal technical coefficients<sup>13</sup> expressed in cubic meter per produced unit.<sup>14</sup> These coefficients were converted into cubic meters per monetary units using Annual Industry Research data for 2009 ([Instituto Brasileiro de Geografia e Estatística, 2011b](#)).

The agriculture sectors' estimates are based on technical coefficients for water withdrawal for irrigated agriculture for 59 different crop products per municipality and per month. These coefficients are presented in liters per second per hectare ( $L s^{-1} ha^{-1}$ ) with 2006 irrigated area<sup>15</sup>. The 59 agricultural products were aggregated into 9 agricultural sectors, and water use technical coefficients in  $m^3/10^6 USD$  were obtained by taking the ratio between water withdrawal ( $m^3/year$ ) and total output ( $10^6 USD$ ) from the input–output matrix. It is important to note that the agriculture sector (as well as the livestock sectors and water supply sector, see below) has water withdrawal coefficients that are different for each of the 23 regions. They reflect the geographic differences among regions (as rain or soil type), thereby addressing the common drawback of using national average water coefficient of large countries ([Biewald et al., 2014](#)).

The estimates of the livestock sectors are based on the [Operador Nacional do Sistema Elétrico and FAHMA/DREER \(2003\)](#) methods, which present per capita water withdrawal (in liters per day) for different animal species. We have estimated water withdrawal using Municipalities Livestock Production data for 2009 ([Instituto Brasileiro de Geografia e Estatística, 2010](#)).

For the water supply sector, we considered that water consumption ( $Q$ ) within a region would be equal to the urban population<sup>16</sup> ( $Pu$ ) of this region multiplied by the average per capita consumption ( $q$ ) of this region. Sao Paulo State regions have an average per capita consumption of  $177.8 L hab^{-1} day^{-1}$ , the rest of Brazil's consumption was based on the national average of  $148.5 L hab^{-1} day^{-1}$  ([Ministério das Cidades, 2011](#)).<sup>17</sup> The average per capita consumption represents the volume of water that was consumed, excluding the exported water volume, and divided by the population attended by the water supply service in the period. It represents thus the daily average per person of the volumes used to satisfy domestic commercial, public and industrial consumption made through the water supply systems. Therefore, water consumption for water supply ( $Q$ ) in  $m^3/year$ , is given by:

$$Q = Pu \times q \frac{365}{1000} \quad (13)$$

Water withdrawal for water supply is, in turn, superior to the water consumption ( $Q$ ) once there is significant water loss in the distribution process. The water loss index (WLI) corresponds to the difference between the net water production (volume available for distribution after treatment) and the legitimate and effectively consumed water volume, as a percentage of net water production. According to [Ministério das Cidades \(2011\)](#), the average WLI for the water supply firms from SNIS was 41.6% in 2009. In Sao Paulo State, this index was 34.8%. Therefore, the annual water withdrawal ( $Qw$ ) was obtained from the relation:

$$Qw = \frac{Q}{1 - WLI} \quad (14)$$

where  $Qw$  is water withdrawal for water supply, in  $m^3/year$ ,  $Q$  is water consumption for water supply, in  $m^3/year$  and  $WLI$  is the water loss index (%).

<sup>13</sup> [Fundação Banco do Brasil et al. \(2011\)](#) also presents water consumption and return technical coefficients for industry and agriculture sectors.

<sup>14</sup> [Fundação Banco do Brasil et al. \(2011\)](#) have highlighted that the economic activities classification used presents a limitation to this kind of study, once there are many industrial plants that produce different kinds of products, such as aluminum-bauxite integrate plants or paper and pulp integrate plants. Besides, industries with a high diversity of products and processes, such as the chemistry industry, the technical coefficients are limited to its group average data. Despite this fact, data presented in this study were considered sufficiently adequate to give policy makers some insights into water resources management.

<sup>15</sup> We have considered that there was no substantial increase in irrigated areas between 2006 (Agricultural Census, from which we used irrigated area) and 2009 (year of the I-O data).

<sup>16</sup> In 2009, 95,2% of Brazilian urban population had access to water supply services. On the other hand, less than 10% of the rural population had access to these services ([Ministério das Cidades, 2011](#)).

<sup>17</sup> 2009s data.

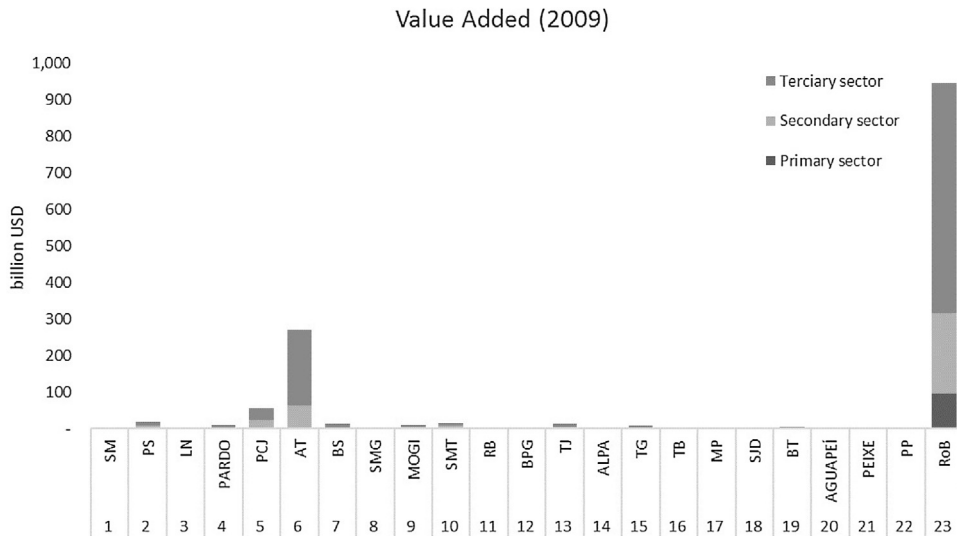


Fig. 3. Total value added from 23 regions (2009).

We considered that the water consumption for urban cleaning and construction services are included in the water supply system,<sup>18</sup> thus their direct water consumption was null. The same assumption was made for all other non-water intensive sectors.

#### 4. Results and discussion

In the following subsections we first present the economic dependence among regions describing their productive structure and their output multipliers. Water use estimates are presented next, followed by total (direct and indirect) water withdrawal per region and per sector and by virtual water trade balance and flows.

##### 4.1. Productive structure

In Fig. 3 we can compare the importance of each region relative to its contribution to total value added. Region 23–RoB (rest of Brazil) presents higher values when compared to others, as expected. The Alto Tiete (6-AT) region presents the highest contribution to the State’s total value added, with more than 270 billion USD (59% of State’s total value added), mostly in services sectors. Primary sectors in Sao Paulo regions have only a minor participation in the value added when compared to the industry or services sectors.

For all Sao Paulo regions, a significant part of its own total output (more than 40%) is destined to other regions’ final demand and intermediary consumption. Despite this fact, the majority of the regions are in a trade deficit situation (Fig. 4).

Trade flows (exports + imports) connects all regions to one another, but stronger trade flows connects rest of Brazil and region 6-AT to other Sao Paulo state regions (Fig. 5). Detailed results are presented in Appendix 2.

##### 4.2. Output and value added multipliers

Fig. 6 shows Leontief inverse matrix<sup>19</sup> for the 23 regions. All 23 regions rely on the rest of Brazil’s (region-23) supply for its own output. In Sao Paulo state, the only region which may be highlighted as supplier is region 6-AT, particularly in services sector. In WRMU 5–PCJ (Piracicaba/Capivari/Jundiai), this flow can be observed to some

<sup>18</sup> 30 to 45% of water and sewage sector is destined to final demand. The rest of it is incorporated to other sector’s productive processes, such as construction and urban cleaning, for example.

<sup>19</sup> We have subtracted the unitary value from the diagonal for better visualization.

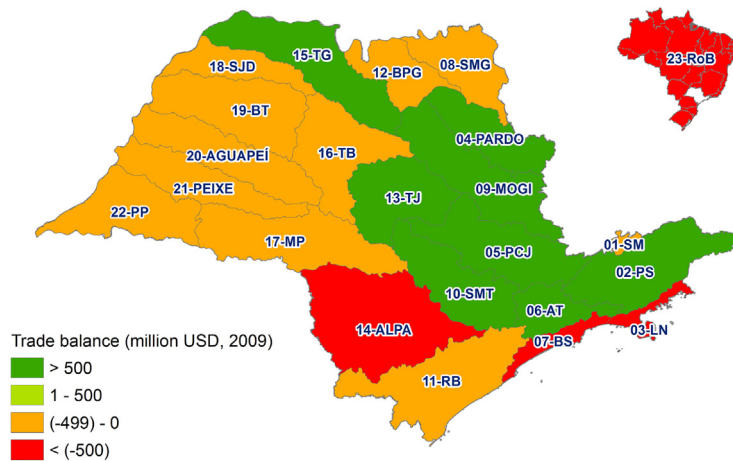


Fig. 4. Sao Paulo State WRMU's trade balance (trade balance includes trade with rest of Brazil, but not with the rest of the world).

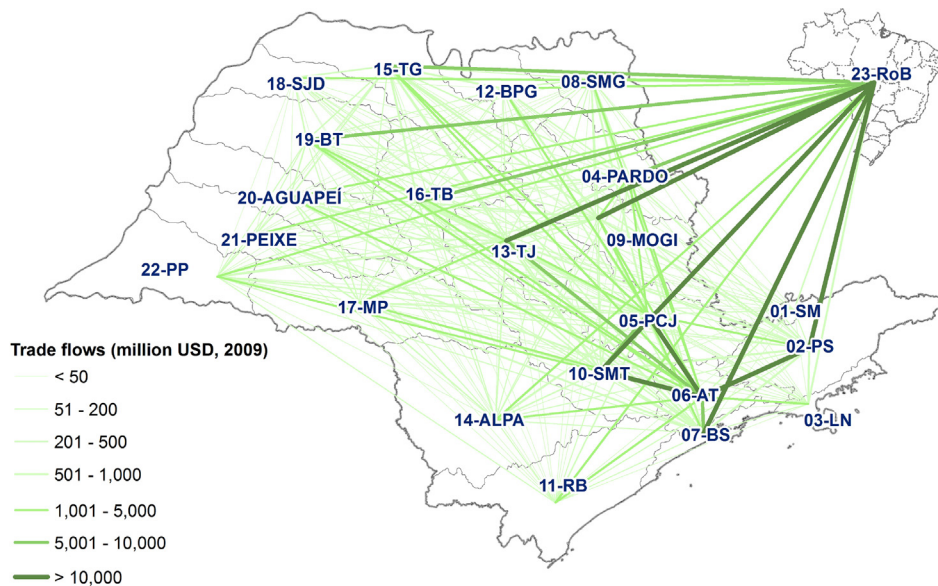


Fig. 5. Sao Paulo State WRMU's trade flows (exports + imports).

specific WRMUs. It is also possible to identify inter-sectorial flows within a region, as we can see in region 2-PS (Paraíba do Sul), or region 7-BS (Baixada Santista). In all these cases, the services sector is the strongest supplier, possibly because of the sectoral aggregation level used in this study which prioritized the disaggregation of the water intensive sectors.

Fig. 7 presents region 6-AT (right side) and 23-RoB (left side) output multipliers, decomposed by region. All other regions were grouped in one region called RoSP (rest of Sao Paulo).

Overall, we cannot see big differences between the regions,<sup>20</sup> except for the sectors that do not exist in Alto Tiete (such as 1-Rice or 3-Sugarcane, which present a multiplier = 1). Despite its similarities, it can also be noticed that the multiplier effects exceeds the WRMU's geographical limits. As an example, taking the case of Alto Tiete in Fig. 7, we can observe that a significant part of the multiplier effect from many sectors occurs in the rest of Sao Paulo State as

<sup>20</sup> This similarity is due to the regional input–output disaggregation method, *i.e.*, due to the lack of data and the similar level of development in the majority of the municipalities in Sao Paulo state, as an initial hypothesis of the disaggregation process it is assumed that the economic productive structure of a given sector is the same in all the municipalities in which this sector is present.

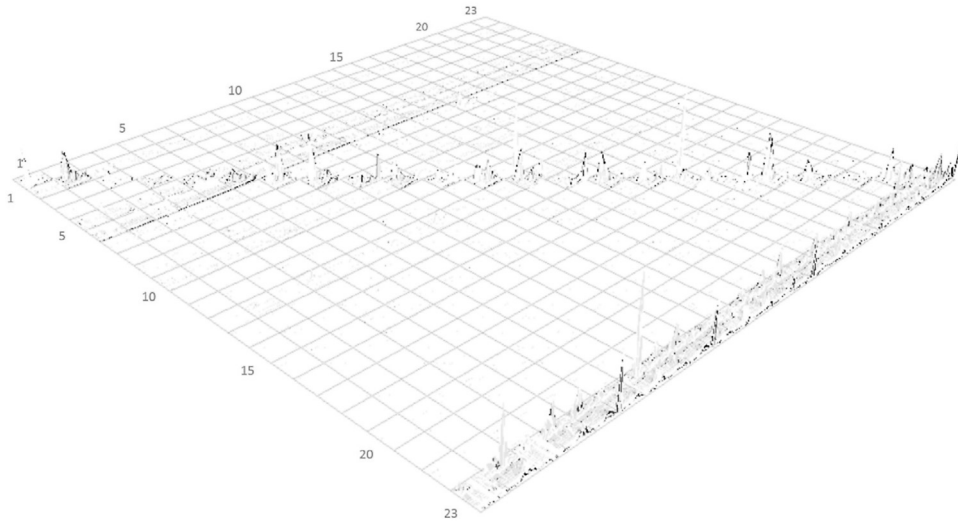


Fig. 6. Interregional Leontief inverse matrix (B). Note: We have subtracted the unitary value from the diagonal for better visualization.

well as in rest of Brazil, indicating that an increase in the final demand of this region can affect the rest of Brazil and other WRMU's.

#### 4.3. Water use estimates

Fig. 8 shows the highest estimated water withdrawal direct coefficients for 20 sectors.<sup>21</sup> Water production and supply/Sewage treatment sector, as well as agriculture related sectors such as rice and sugar cane are the ones with higher coefficients. It is interesting to notice that, despite the technological and aggregation differences, some of our coefficients are similar to that estimated by Mubako et al. (2013) for the states of California and Illinois in 2008. Their estimates range from approximately 46,000 to 900,000 m<sup>3</sup>/10<sup>6</sup> USD for crops, depending on the irrigation intensity of the region. Livestock also appears with high coefficients, similar to the ones estimated by Mubako et al. (2013). In the mining sector, we can highlight Non-metal mining and Coal mining sectors. In industry, Ethanol, Pulp and Sugar manufacturing sectors are the ones with higher coefficients.<sup>22</sup> In general, higher coefficients appear in sectors that uses a large quantity of water in their productive processes, but that also presents relatively low values of total output (in monetary terms).

#### 4.4. Direct and indirect water withdrawal

Table 1 presents the total (direct and indirect) water withdrawal for each of the 23 regions from the producer's perspective.

The results show that Alto Tiete's total water withdrawal is the highest among Sao Paulo State WRMUs, with 2.4 billion m<sup>3</sup> of water. On the one side, about half of this water withdrawal (1.2 billion m<sup>3</sup> of water)<sup>23</sup> is for the consumption of goods and services for the Alto Tiete region itself. On the other side, about 27% of this water withdrawal (635 million m<sup>3</sup> of water) is for the consumption of goods and services in the rest of Brazil, *i.e.* nearly 27% of the water withdrawn in Alto Tiete is sent to the rest of Brazil embedded in goods and services. Analogously, 268 million m<sup>3</sup> and 278 million m<sup>3</sup> of water are exported to the rest of the world and for the final demand of the rest of Sao Paulo. Apart from its

<sup>21</sup> Water withdrawal direct coefficients for 83 sectors are presented in the Appendix in table format.

<sup>22</sup> A comparison of the mining and industry coefficients with the ones estimated by Mubako et al. (2013) is ambiguous because these authors used a highly aggregated input–output matrix, with only 8 sectors.

<sup>23</sup> It is important to notice that the water withdrawal has to be interpreted as the required amount for the output in the period; a significant portion of Alto Tiete's water requirements comes from Piracicaba/ Capivari/Jundiai region through Cantareira System.

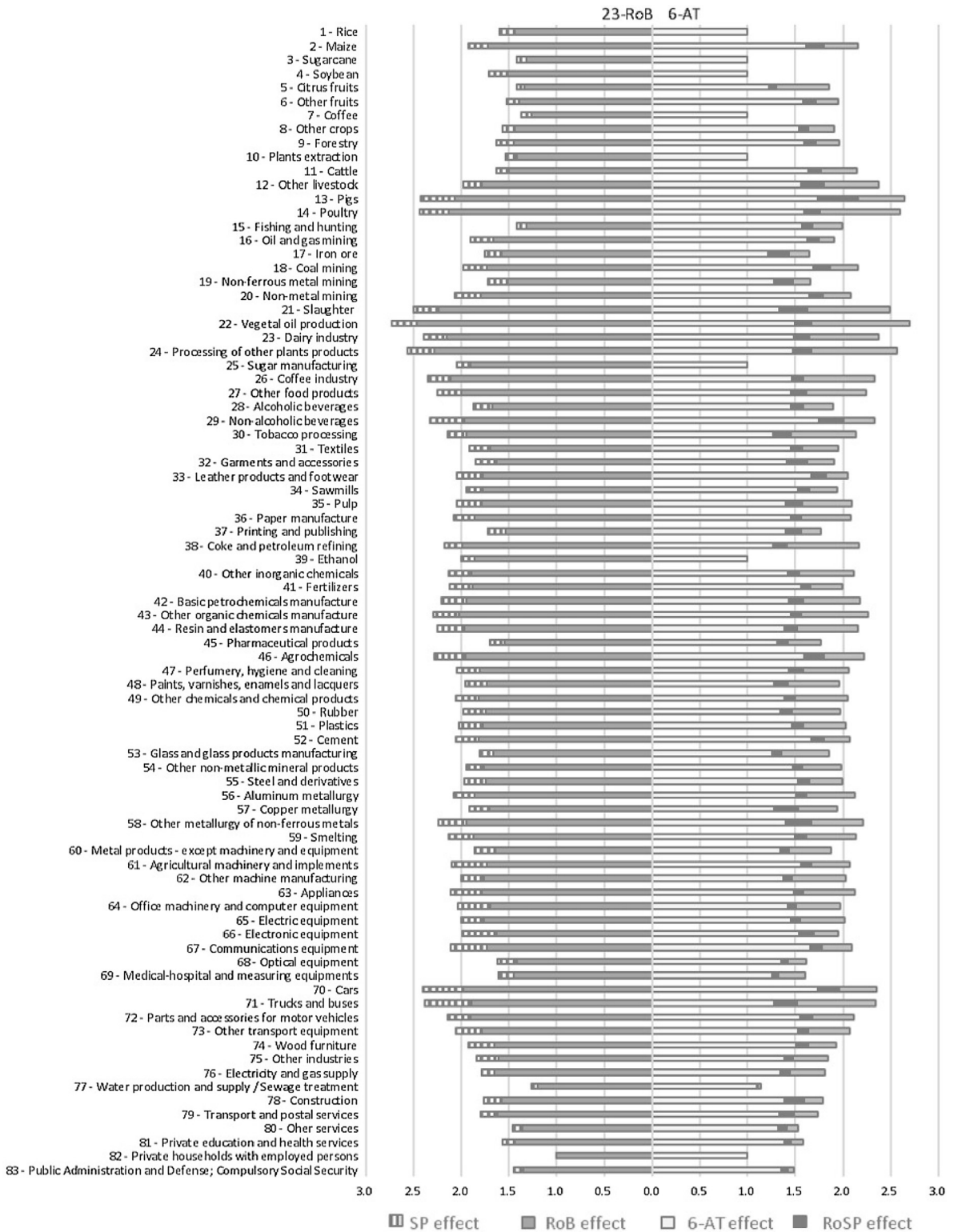


Fig. 7. Alto Tiete (6-AT) and rest of Brazil (23-RoB) output multipliers.

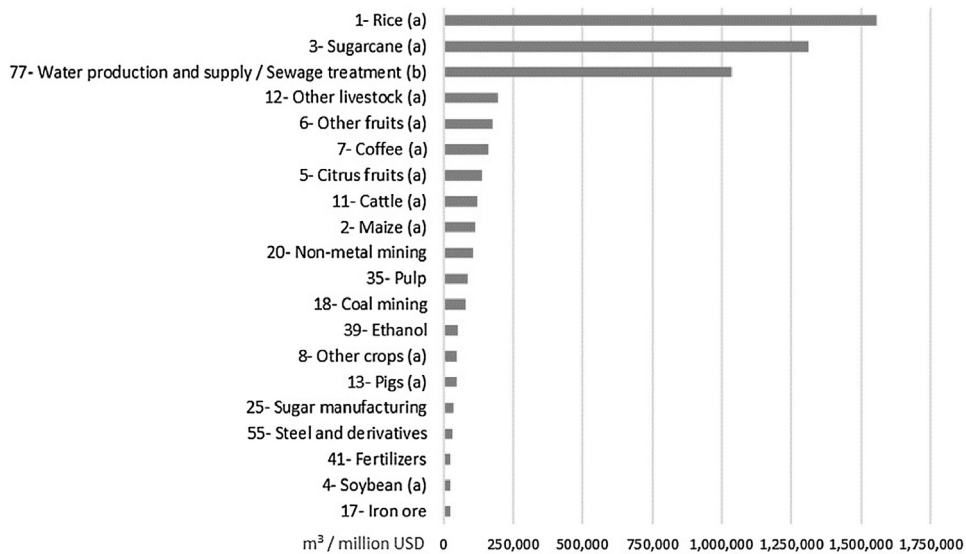


Fig. 8. Water withdrawal direct coefficients (in  $\text{m}^3/10^6$  USD). Note: (a) Agriculture related sectors have different coefficients for each region, reflecting their geographical differences. The value presented is the average coefficient between regions, weighted for the sector output in the region. See Appendix 3 for regional coefficients from these sectors. (b) Water production and supply/Sewage treatment coefficients are different for each region, depending on the resident urban population, on per capita water consumption and on water loss index. The value presented is the average between regions, weighted for the sector output in the region. See Appendix 3 for regional coefficients from this sector.

Table 1

Total (direct and indirect) water withdrawal per region – Producer's perspective – 2009.

	Region $r$	Total water withdrawal in region $r$ due to region $r$ 's final demand ( $\text{hm}^3$ )	Total water withdrawal in region $r$ due to exports ( $\text{hm}^3$ )	Total water withdrawal in region $r$ due to RoSP's final demand ( $\text{hm}^3$ )	Total water withdrawal in region $r$ due to RoB's final demand ( $\text{hm}^3$ )	Total water withdrawal $wr^R$ ( $\text{hm}^3$ )	Population (hab)	Per capita total water withdrawal ( $\text{m}^3/\text{hab}$ ) – producer's perspective
1	SM	4.7	0.2	0.5	1.1	6.6	64,367	101.9
2	PS	93.5	61.4	53.0	108.6	316.5	1,991,602	158.9
3	LN	22.3	0.5	2.3	2.6	27.6	276,863	99.8
4	PARDO	242.1	154.9	267.3	209.8	874.1	1,060,000	824.7
5	PCJ	268.9	115.9	150.5	266.4	801.7	5,053,262	158.7
6	AT	1185.1	267.5	278.4	635.1	2366.1	19,610,845	120.7
7	BS	110.0	52.2	30.0	55.1	247.4	1,668,428	148.3
8	SMG	81.9	122.1	83.3	126.9	414.1	689,001	601.0
9	MOGI	148.0	323.3	195.2	231.1	897.6	1,501,066	598.0
10	SMT	79.4	35.7	56.6	90.1	261.8	1,820,829	143.8
11	RB	21.2	1.6	3.9	8.8	35.6	379,867	93.6
12	BPG	40.4	238.4	56.3	119.1	454.2	333,388	1362.3
13	TJ	135.7	147.7	178.3	192.6	654.3	1,489,749	439.2
14	ALPA	56.1	34.9	28.1	58.5	177.7	734,611	241.9
15	TG	128.3	140.0	132.1	172.8	573.2	1,251,897	457.9
16	TB	41.8	58.0	57.5	87.7	244.9	518,356	472.5
17	MP	76.0	104.0	66.2	104.6	350.7	675,632	519.1
18	SJD	12.8	21.0	15.2	28.5	77.5	155,711	497.5
19	BT	73.5	149.5	117.0	179.6	519.6	740,671	701.5
20	AGUAPEI	48.9	47.0	51.7	84.3	231.9	604,125	383.8
21	PEIXE	50.6	46.9	48.0	60.0	205.5	263,726	779.2
22	PP	37.1	23.4	23.7	54.5	138.8	500,043	277.5
	Total SP	4853.5	2145.9	–	2878.0	9877.4	41,384,039	238.7
23	RoB	31,142.2	8476.1	5043.5	–	44,661.8	150,062,809	297.6

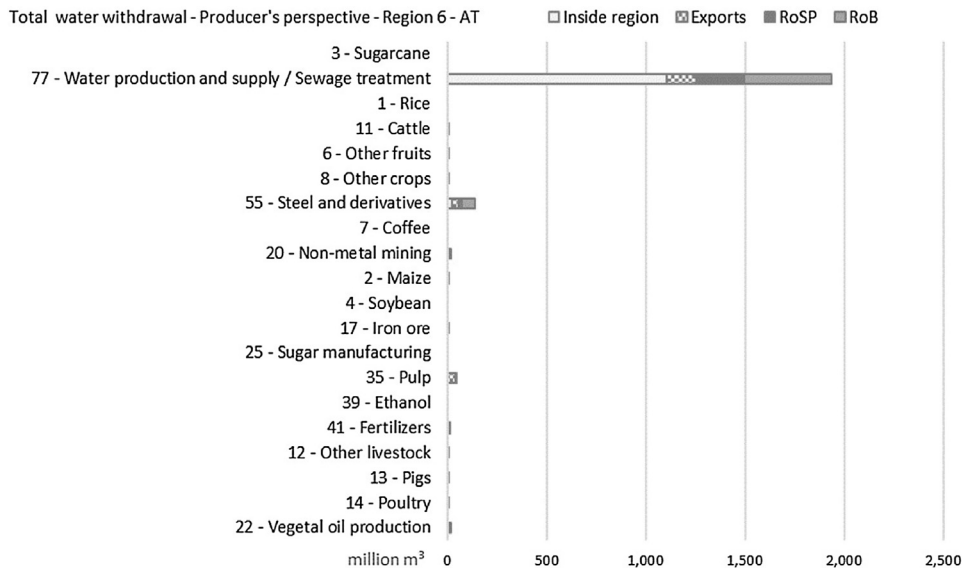


Fig. 9. Total (direct and indirect) water withdrawal in Alto Tiete region (6) due to inside region/exports/RoSP/RoB's final demand – Selected sectors – Producer's perspective – 2009.

relatively high water withdrawal when compared to other Sao Paulo state WRMUs, per capita total water withdrawal is relatively low in Alto Tiete region, around  $121 \text{ m}^3/\text{hab}$ , nearly half of the state's average ( $239 \text{ m}^3/\text{hab}$ ).

As a group, Sao Paulo State's (regions 1–22) total water withdrawal was 9.9 billion  $\text{m}^3$  of water in 2009, and 29% of this withdrawal (2.9 billion  $\text{m}^3$  of water) was due to the rest of Brazil's final demand. In its turn, rest of Brazil's total withdrawal was 44.7 billion  $\text{m}^3$  in the same period. From these 44.7 billion, only 5 billion (11%) was withdrawn due to Sao Paulo state's final demand. When comparing these values, it becomes clear that Sao Paulo state is a net importer of water embedded in goods and services from the rest of Brazil.

Detailing Alto Tiete region (Fig. 9), we can verify that the highest direct and indirect water withdrawal is found in the water production and supply sector, which accounts for 82% of all withdrawal in the period. Exports to the rest of the world, RoSP and RoB are responsible for a significant portion of water withdrawn from Alto Tiete for the water production and supply sector, because their final demand is composed of goods and services from region 6-AT that requires this use. Apart from some industry sectors such as 35-Pulp and 55-Steel and derivatives, all other sectors present very low direct and indirect water withdrawal.

The rest of Brazil shows a quite different situation (Fig. 10). Despite the high total water withdrawal presented by water production and supply sector (as in Alto Tiete), some agriculture sectors stand out in terms of their withdrawal level, such as 1-Rice, 3-Sugarcane and 11-Cattle. All agriculture related sectors together account for 65% of all water withdrawal.

Table 2 presents the total (direct and indirect) water withdrawal for each of the 23 regions from the consumer's perspective. From this point of view, region 6-AT's final demand is responsible for the withdrawal of 4.6 billion  $\text{m}^3$  of water, and only 26% of this volume is withdrawn from region 6-AT itself. Per capita total water withdrawal in region 6-AT is  $232.5 \text{ m}^3/\text{hab}$ , which is smaller than Sao Paulo State's average and also smaller than regions 5-PCJ and 7-BS indicating a relative saving in services of water from region 6-AT final demand. This index presents a lower variation among regions than the producer's perspective, once it is related to the resident population consumption pattern instead of production pattern.<sup>24</sup> This similarity is relevant for the discussion concerning fair allocation of water in the context of real water transfers.

The Alto Tiete region (Fig. 11) case shows that the highest direct and indirect water withdrawal is found in water production and supply sector. However, agriculture products' consumption leads to a high water withdrawal, especially

<sup>24</sup> Our results for the Brazilian case is approximately  $230 \text{ m}^3/\text{hab}$ , which is much less than the  $1619 \text{ m}^3/\text{hab}$  estimated by da Silva et al. (2016). The difference relies on the fact that these authors included rain water, or green water footprint, in their estimates. In water footprint framework, rain water (green water component) accounts for the majority of the water footprint.

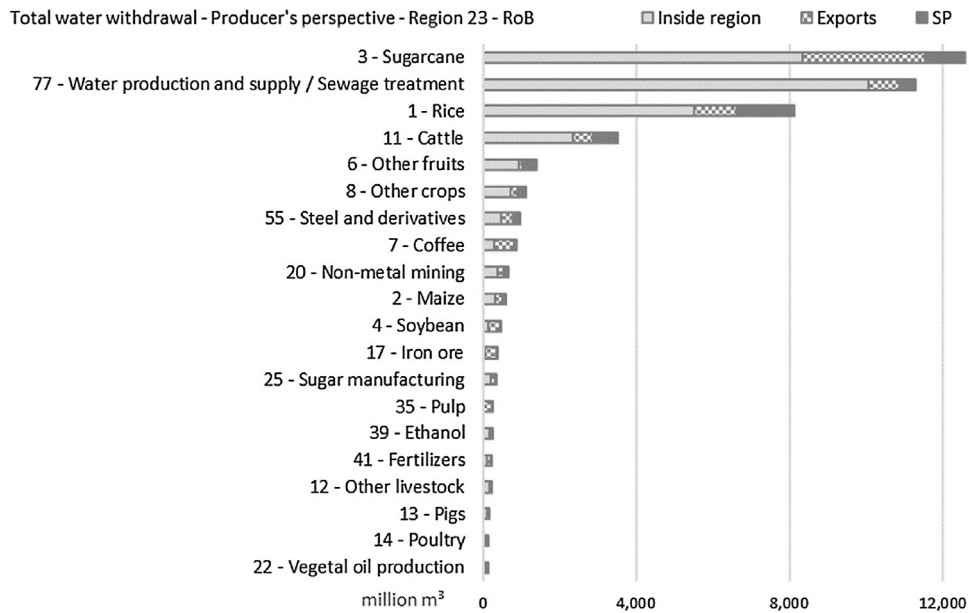


Fig. 10. Total (direct and indirect) water withdrawal in region 23 – rest of Brazil due to inside region/exports/SP's final demand – Selected sectors – Producer's perspective – 2009.

Table 2

Total (direct and indirect) water withdrawal per region – Consumer's perspective – 2009.

	Region $r$	Total water withdrawal in region $r$ due to region $r$ 's final demand (hm <sup>3</sup> )	Total water withdrawal in RoSP due to region $r$ 's final demand (hm <sup>3</sup> )	Total water withdrawal in RoB due to region $r$ 's final demand (hm <sup>3</sup> )	Total water withdrawal $wu^s$ (hm <sup>3</sup> )	Population (hab)	Per capita total water withdrawal (m <sup>3</sup> /hab) – consumer's perspective
1	SM	4.7	2.5	6.5	13.7	64,367	212.7
2	PS	93.5	84.4	228.0	405.9	1,991,602	203.8
3	LN	22.3	13.8	28.1	64.3	276,863	232.2
4	PARDÓ	242.1	59.7	133.6	435.4	1,060,000	410.7
5	PCJ	268.9	397.5	635.9	1302.3	5,053,262	257.7
6	AT	1185.1	816.2	2558.2	4559.5	19,610,845	232.5
7	BS	110.0	93.7	203.9	407.7	1,668,428	244.3
8	SMG	81.9	18.2	73.3	173.3	689,001	251.6
9	MOGI	148.0	62.3	160.6	371.0	1,501,066	247.1
10	SMT	79.4	71.0	199.5	349.8	1,820,829	192.1
11	RB	21.2	12.6	32.9	66.8	379,867	175.7
12	BPG	40.4	19.5	37.6	97.5	333,388	292.6
13	TJ	135.7	65.5	168.5	369.7	1,489,749	248.1
14	ALPA	56.1	21.0	66.4	143.5	734,611	195.3
15	TG	128.3	39.8	144.5	312.6	1,251,897	249.7
16	TB	41.8	18.8	57.1	117.7	518,356	227.1
17	MP	76.0	20.6	69.4	165.9	675,632	245.6
18	SJD	12.8	6.4	17.5	36.7	155,711	235.6
19	BT	73.5	26.5	79.5	179.5	740,671	242.4
20	AGUAPEI	48.9	24.0	62.1	135.0	604,125	223.4
21	PEIXE	50.6	7.5	26.1	84.1	263,726	318.9
22	PP	37.1	13.9	54.2	105.2	500,043	210.4
	Total SP	4853.5	–	5043.5	9897.1	41,384,039	239.2
23	RoB	31,142.2	2878.0	–	34,020.2	150,062,809	226.7



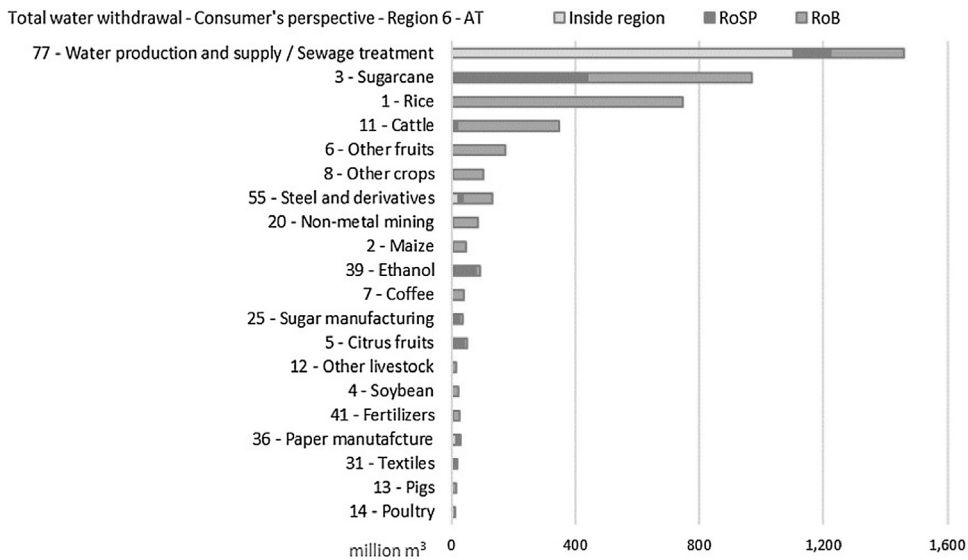


Fig. 11. Total (direct and indirect) water withdrawal due to (6) Alto Tiete region's final demand – selected sectors – consumer's perspective – 2009.

in other regions. The majority of water consumed in the rest of Sao Paulo (RoSP) from Alto Tiete's final demand are related to ethanol fuel and the sugar productive chain (involving sugarcane, ethanol and sugar manufacturing sectors) and citrus fruits. Analogously, Alto Tiete's final demand induces water withdrawal in the rest of Brazil from the consumption of other agriculture products, such as those produced by rice, cattle, other fruits and other crops sectors. Going back to ethanol and sugar, it is worth mentioning that the state's government has introduced some regulations related to these sectors' water use: since 2008, new ethanol/sugar plants in Sao Paulo state are subject to a maximum water use level of  $1 \text{ m}^3/\text{ton}$  of processed sugarcane<sup>25</sup>. This maximum level is even lower ( $0.7 \text{ m}^3/\text{ton}$  of processed sugarcane) in some areas, and in some areas considered inadequate for ethanol/sugar plants, so that they will not receive an environmental license (Determination No. 88/2008 from State's Environment Secretariat). The ethanol and sugar industries point out in return the complexities concerning the water–food–energy nexus in Brazil, which is well presented in Castillo et al. (2017).

The rest of Brazil (Fig. 12) shows a similar pattern of water withdrawal, except that the majority of the water is withdrawn from the region 23 itself.

#### 4.5. Virtual water flows

Virtual water trade balance shows a quite different picture (Fig. 13).

Regions with a lower per capita water availability (5-PCJ, 6-AT and 10-SMT in Fig. 1) are also the ones with a virtual water trade deficit. These regions also present trade surplus in monetary terms, suggesting that their exports are composed by non-water-intensive products, while their imports are water-intensive products, which appears as an efficient water resource allocation in these regions.

However, our results also show water-scarce regions sending virtual water to water-rich regions, such as region 13-TJ. Despite poor per capita water availability they send their scarce water to other regions. It may also be noted that regions with high per capita water availability (1-SM, 3-LN, 11-RB and 14-ALPA) are not the ones presenting virtual water surplus. These results suggest that Sao Paulo State's virtual water flows appear to be not driven by water availability but by other factors, which could be arable land area for crop production, as proposed by Kumar and Singh (2005), labour, technology (Hoekstra and Hung, 2005) and differences in state's policies regarding different economic activities (Guan and Hubacek, 2007). Other empirical studies have also shown that virtual water trade is not driven by water scarcity (Chapagain and Hoekstra, 2008), hence, the virtual water perspective cannot be used alone as a criteria for designing public policies (Wichelms, 2010).

<sup>25</sup> Brazilian average is  $2 \text{ m}^3/\text{ton}$  of processed sugarcane

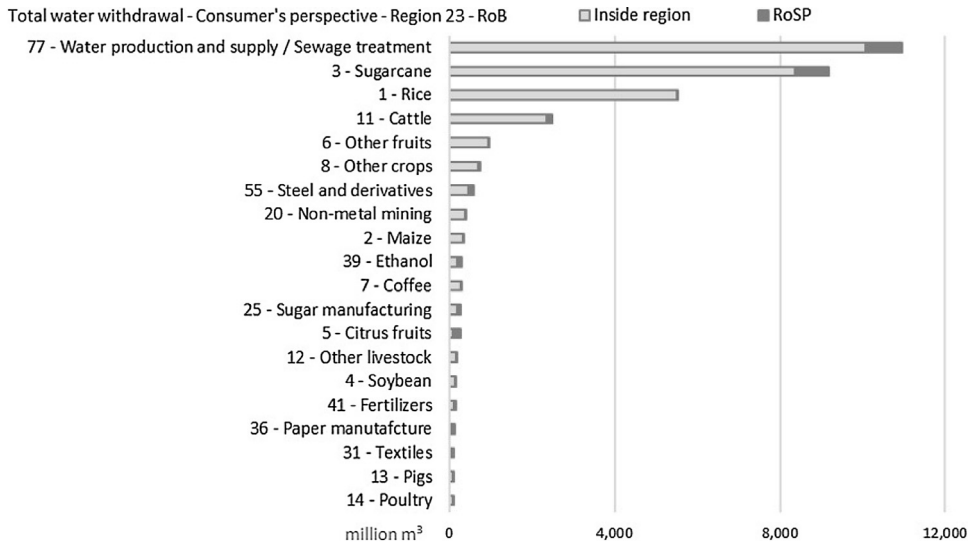


Fig. 12. Total (direct and indirect) water withdrawal due to (23) rest of Brazil region’s final demand – selected sectors – consumer’s perspective – 2009.

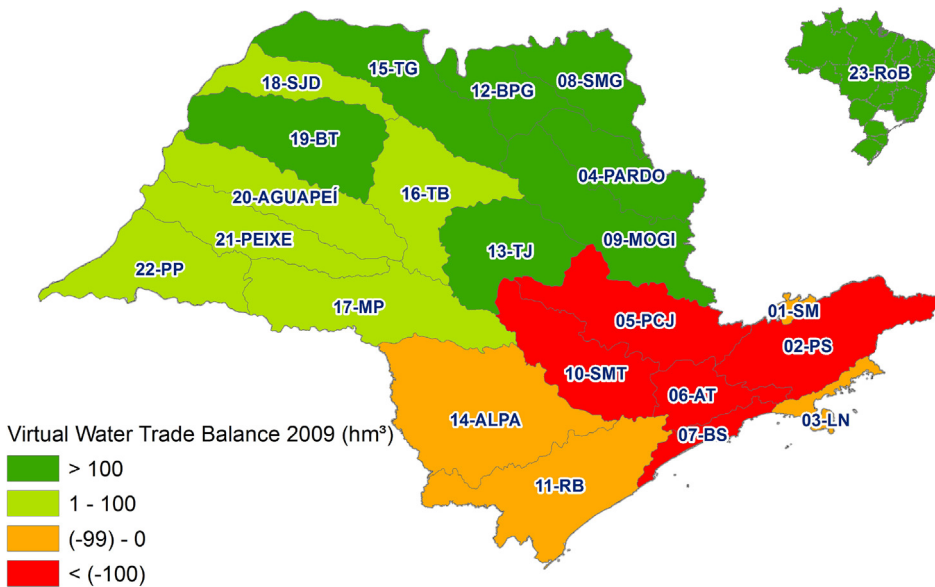


Fig. 13. Virtual water balance (withdrawal) (virtual water trade balance includes trade with rest of Brazil, but not with the rest of the world).

Trade flows (exports + imports) connects all regions to one another, but stronger virtual water trade flows connects Sao Paulo state’s regions to rest of Brazil and region 6-AT to other Sao Paulo state’s regions (Fig. 14). Detailed results are presented in Appendix 4.

Fig. 15 shows virtual water trade flows among region 6-AT and other selected regions. It is interesting to notice that region 6-AT sends 149.6 hm³ of virtual water to region 5-PCJ, while region 5-PCJ sends back 98 hm³ of virtual water, resulting in a water trade surplus of 51.6 hm³ for 6-AT in relation to 5-PCJ over the year. This transfer rate is equivalent to 1.64 m³/s, which would represent only a small share of the amount of real water that comes through the Cantareira System to Alto Tiete (31 m³/s). If virtual water trade can compensate at least a small part of real water transfer among region 6-AT and region 5-PCJ, this would not be the case among regions 6-AT and region 7-BS. In the latter case, region 6-AT sends a higher amount of virtual water do region 7-BS than it receives from this region, while sending 22.5 m³/s of real water for hydropower generation through a transboundary infrastructure. A significant portion of the virtual water trade deficit observed in region 6-AT can be explained by trade among this region and region 23-RoB.

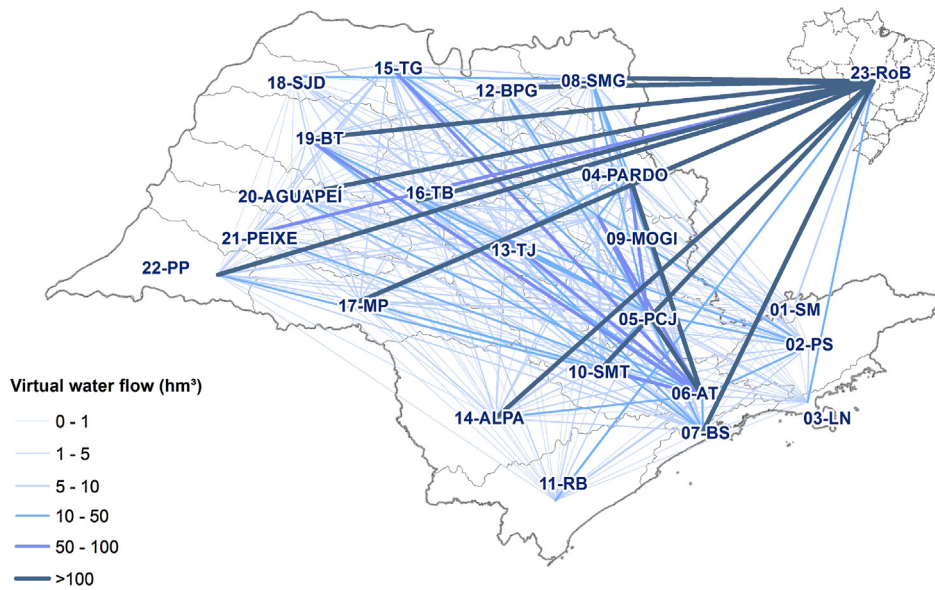


Fig. 14. Virtual water flows (withdrawal)(exports + imports).

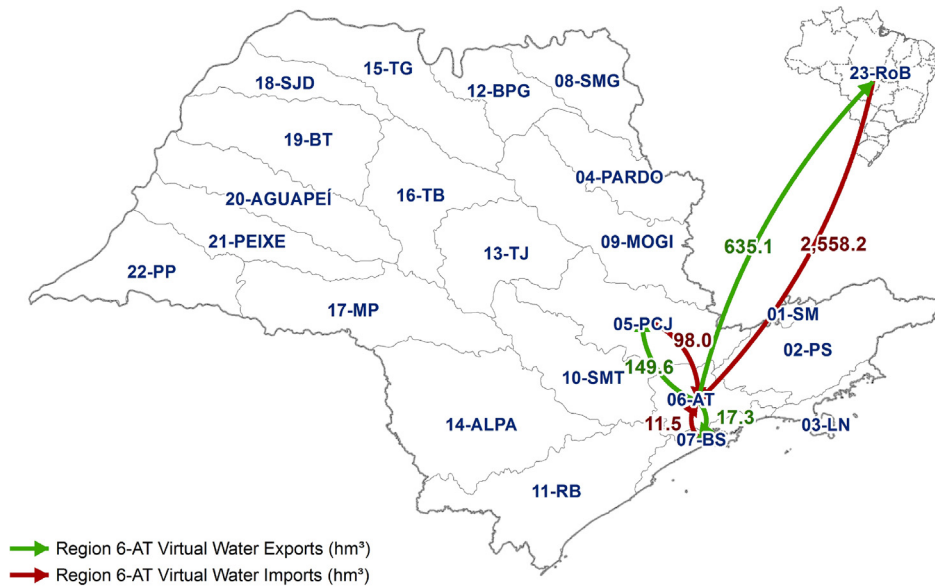


Fig. 15. Virtual water flows (withdrawal) among region 6-AT and selected regions.

The comparison between real water transfer and virtual water trade is possible because our estimates are based on water withdrawal. The water footprint framework is seen as offering a more holistic view due to its green and gray components, but at the same time, assessing maximum sustainable water footprint and water footprint benchmarks is still problematic (Hoekstra, 2017). Nonetheless, water withdrawal is a variable that is subject to a license from the government, so that quantitative measures related to water withdrawal can be more easily understood and used in future policy prescriptions.

### 5. Concluding remarks

In this paper, we examined the regional scale of water scarcity, consumption and trade, by analyzing the economic and trade structure among different Water Resources Management Units (WRMU) at the state of Sao Paulo in Brazil,

focusing on the water-scarce region of Alto Tiete. We have quantified direct and indirect water uses among these regions, showing up the virtual water flow among them.

It would be expected that once water is recognized as a scarce factor for production, regions with higher water availability would present comparative advantages in relation to those with a lower availability. However, our results show that many virtual water flows among Sao Paulo State's WRMUs are not driven by water availability, but by other factors, *e.g.*, political and economic power and old productive structures remaining from the time where water was not considered a scarce resource.

As shown in the paper, a better understanding of the socioeconomic relations that overlays the geographical limits of a water basin region can be obtained by using an interregional input–output model, in our example estimated for the Sao Paulo State WRMUs. Using the results from the IRIO model it is possible to measure how water withdrawal in one region may be influenced by consumption in another region. Such links and results are important inputs to improve the dialogue between government, producers and consumers from different regions and can be used to obtain integrate solutions for water scarcity problems.

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### Acknowledgements

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### Appendix A.

Table A.3  
83 industries.

	Code	Sector
Primary sectors	1	Rice
	2	Maize
	3	Sugarcane
	4	Soybean
	5	Citrus fruits
	6	Other fruits
	7	Coffee
	8	Other crops
	9	Forestry
	10	Plants extraction
	11	Cattle
	12	Other livestock
	13	Pigs
	14	Poultry
	15	Fishing and hunting
	16	Oil and gas mining
	17	Iron ore
	18	Coal mining
	19	Non-ferrous metal mining
	20	Non-metal mining
Secondary sectors	21	Slaughter
	22	Vegetal oil production
	23	Dairy industry
	24	Processing of other plants products
	25	Sugar manufacturing

Table A.3 (Continued)

	Code	Sector
	26	Coffee industry
	27	Other food products
	28	Alcoholic beverages
	29	Non-alcoholic beverages
	30	Tobacco processing
	31	Textiles
	32	Garments and accessories
	33	Leather products and footwear
	34	Sawmills
	35	Pulp
	36	Paper manufacture
	37	Printing and publishing
	38	Coke and petroleum refining
	39	Ethanol
	40	Other inorganic chemicals
	41	Fertilizers
	42	Basic petrochemicals manufacture
	43	Other organic chemicals manufacture
	44	Resin and elastomers manufacture
	45	Pharmaceutical products
	46	Agrochemicals
	47	Perfumery, hygiene and cleaning
	48	Paints, varnishes, enamels and lacquers
	49	Other chemicals and chemical products
	50	Rubber
	51	Plastics
	52	Cement
	53	Glass and glass products manufacturing
	54	Other non-metallic mineral products
	55	Steel and derivatives
	56	Aluminum metallurgy
	57	Copper metallurgy
	58	Other metallurgy of non-ferrous metals
	59	Smelting
	60	Metal products - except machinery and equipment
	61	Agricultural machinery and implements
	62	Other machine manufacturing
	63	Appliances
	64	Office machinery and computer equipment
	65	Electric equipment
	66	Electronic equipment
	67	Communications equipment
	68	Optical equipment
	69	Medical-hospital and measuring equipments
	70	Cars
	71	Trucks and buses
	72	Parts and accessories for motor vehicles
	73	Other transport equipment
	74	Wood furniture
	75	Other industries
	76	Electricity and gas supply
	77	Water production and supply / Sewage treatment
	78	Construction
Tertiary sectors	79	Transport and postal services
	80	Other services
	81	Private education and health services
	82	Private households with employed persons
	83	Public Administration and Defense; Compulsory Social Security

Table A.4  
Trade among regions (10<sup>6</sup> USD, 2009).

Region	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Trade Balance	
1	–	32	0	1	12	77	3	0	1	6	0	0	0	0	1	0	0	0	0	0	0	0	0	147	–100
2	36	–	357	136	2066	5950	219	44	175	382	43	29	295	58	131	39	61	9	37	62	14	38	13,544	1354	
3	0	402	–	1	18	306	60	1	2	4	22	0	1	1	3	1	1	1	1	1	1	1	451	–579	
4	4	125	12	–	553	1555	149	689	1238	119	24	218	314	46	247	109	64	21	92	242	17	36	4960	1703	
5	39	2254	168	1229	–	22,698	1781	494	1700	2662	146	166	1379	445	764	438	275	54	323	277	94	282	37,685	16,949	
6	160	8721	753	2822	23,883	–	5473	807	2778	8310	1014	897	3343	2096	2920	1279	1027	249	1414	993	591	1431	130,532	78,793	
7	2	490	64	61	943	2923	–	125	415	360	105	169	284	47	100	288	424	7	136	31	10	80	7577	–532	
8	2	39	7	173	154	478	172	–	130	29	8	86	54	31	35	39	28	5	26	13	7	10	2796	–292	
9	8	354	11	722	1314	2130	322	295	–	175	15	203	307	65	236	231	71	13	115	129	20	83	8237	1045	
10	12	542	36	154	2979	5984	247	48	187	–	114	30	248	284	167	35	89	11	390	78	24	53	11,120	2953	
11	0	50	3	20	61	466	48	8	11	61	–	3	15	30	19	2	7	1	8	4	3	44	933	–401	
12	1	21	2	151	89	312	103	153	357	26	2	–	76	7	135	99	15	5	33	9	16	9	1781	–340	
13	3	586	13	257	910	2394	270	94	495	253	19	49	–	174	635	310	354	16	750	199	47	85	8016	3057	
14	1	52	2	28	205	740	118	21	38	198	29	5	57	–	23	15	162	1	11	27	6	19	2557	–755	
15	3	92	8	145	336	1180	104	51	758	95	24	439	179	63	–	512	67	183	333	105	30	50	5284	639	
16	1	90	2	49	306	621	155	26	95	37	4	70	144	49	198	–	140	10	96	42	8	29	3144	–320	
17	2	26	6	22	149	587	170	13	40	92	12	11	225	223	38	45	–	10	56	102	114	108	2818	–290	
18	0	5	4	5	27	179	10	3	3	3	0	4	8	1	64	6	8	–	45	4	1	2	595	–279	
19	1	31	4	38	192	807	120	18	35	52	4	33	468	10	163	117	90	223	–	177	53	47	3406	–154	
20	1	29	3	25	181	451	45	15	34	33	4	7	119	32	124	43	177	8	135	–	185	63	2329	–159	
21	0	15	2	7	53	248	14	6	11	13	3	3	17	8	16	7	86	5	27	119	–	39	1016	–336	
22	1	30	12	11	101	703	49	7	21	30	24	6	431	8	25	41	78	5	53	89	139	–	1961	–74	
23	105	8384	390	3073	23,872	71,908	5539	1695	5487	6944	580	1313	4907	1389	3360	1979	1935	421	2162	1500	673	1390	–	–101,884	

Table A.5  
Water use coefficients to 83 sectors (2009).

Code	Sector	Water withdrawal coefficients (m <sup>3</sup> /10 <sup>6</sup> USD)
1	Rice <sup>a</sup>	1,554,580
2	Maize <sup>a</sup>	115,103
3	Sugarcane <sup>a</sup>	1,309,237
4	Soybean <sup>a</sup>	24,631
5	Citrus fruits <sup>a</sup>	137,897
6	Other fruits <sup>a</sup>	175,171
7	Coffee <sup>a</sup>	160,423
8	Other crops <sup>a</sup>	49,840
9	Forestry <sup>a</sup>	2496
10	Plants extraction	–
11	Cattle <sup>a</sup>	121,792
12	Other livestock <sup>a</sup>	195,283
13	Pigs <sup>a</sup>	49,739
14	Poultry <sup>a</sup>	12,890
15	Fishing and hunting	–
16	Oil and gas mining	–
17	Iron ore	23,687
18	Coal mining	77,975
19	Non-ferrous metal mining	3813
20	Non-metal mining	104,751
21	Slaughter	2049
22	Vegetal oil production	6964
23	Dairy industry	820
24	Processing of other plants products	404
25	Sugar manufacturing	37,322
26	Coffee industry	613
27	Other food products	5856
28	Alcoholic beverages	5034
29	Non-alcoholic beverages	185
30	Tobacco processing	4830
31	Textiles	8184
32	Garments and accessories	538
33	Leather products and footwear	108
34	Sawmills	5
35	Pulp	86,320
36	Paper manufacture	11,760
37	Printing and publishing	140
38	Coke and petroleum refining	1790
39	Ethanol	50,245
40	Other inorganic chemicals	3890
41	Fertilizers	25,654
42	Basic petrochemicals manufacture	10,439
43	Other organic chemicals manufacture	3074
44	Resin and elastomers manufacture	5630
45	Pharmaceutical products	521
46	Agrochemicals	764
47	Perfumery, hygiene and cleaning	605
48	Paints, varnishes, enamels and lacquers	348
49	Other chemicals and chemical products	5742
50	Rubber	2950
51	Plastics	81
52	Cement	2119
53	Glass and glass products manufacturing	1677
54	Other non-metallic mineral products	882
55	Steel and derivatives	34,465
56	Aluminum metallurgy	1573

Table A.5 (Continued)

Code	Sector	Water withdrawal coefficients (m <sup>3</sup> /10 <sup>6</sup> USD)
57	Copper metallurgy	1008
58	Other metallurgy of non-ferrous metals	56
59	Smelting	1678
60	Metal products – except machinery and equipment	318
61	Agricultural machinery and implements	162
62	Other machine manufacturing	122
63	Appliances	455
64	Office machinery and computer equipment	163
65	Electric equipment	13
66	Electronic equipment	76
67	Communications equipment	383
68	Optical equipment	96
69	Medical-hospital and measuring equipments	4
70	Cars	236
71	Trucks and buses	148
72	Parts and accessories for motor vehicles	3
73	Other transport equipment	198
74	Wood furniture	501
75	Other industries	1660
76	Electricity and gas supply	–
77	Water production and supply / Sewage treatment <sup>b</sup>	1,036,809
78	Construction	–
79	Transport and postal services	–
80	Other services	–
81	Private education and health services	–
82	Private households with employed persons	–
83	Public Administration and Defense; Compulsory Social Security	–

<sup>a</sup> Agriculture related sectors have different coefficients for each region, reflecting their geographical differences. The value presented is the average coefficient between regions, weighted for the sector output in the region. See [Table A.6](#) for regional coefficients from these sectors.

<sup>b</sup> Water production and supply/Sewage treatment coefficients are different for each region, depending on the resident urban population, on per capita water consumption and on water loss index. The value presented is the average between regions, weighted for the sector output in the region. See [Table A.6](#) for regional coefficients from this sector.



Table A.6  
Water withdrawal coefficients (m<sup>3</sup>/10<sup>6</sup> USD) per sector<sup>a</sup> for different regions.

Region	1-Rice	2-Maize	3-Sugarcane	4-Soybean	5-Citrus fruits	6-Other fruits	7-Coffee	8-Other crops	9-Forestry	11-Cattle	12-Other livestock	13-Pigs	14-Poultry	77-Water production and supply/Sewage treatment
1	–	27,880	–	–	1805	4893	728	1062	–	104,984	336,250	150,830	8983	1,137,328
2	16,319,804	24,569	147,949	–	22,383	11,124	384	4208	–	61,324	187,949	136,178	10,282	751,754
3	–	–	–	–	–	–	–	–	–	–	–	–	–	1,231,634
4	193,886	267,674	1,499,370	10,190	273,113	13,956	118,036	128,812	–	47,595	89,645	57,754	16,525	959,787
5	1651	78,135	142,728	–	90,678	22,681	57,902	3326	–	48,440	92,956	87,772	16,801	711,970
6	–	633	–	–	4190	11,746	–	440	–	17,567	57,502	40,817	17,872	723,998
7	–	–	–	–	–	8956	–	183	–	18,939	113,811	82,630	–	1,025,396
8	43,264	751,291	432,848	151,458	5834	4885	124,604	71,293	–	61,038	82,845	57,450	16,111	1,104,925
9	59,652	224,580	628,938	7494	167,448	71,369	139,940	34,244	–	46,888	63,556	84,854	14,827	906,668
10	–	65,111	85,095	625	49,844	7045	29,359	6106	–	65,305	110,554	101,939	19,194	710,917
11	42,854	2010	9405	–	3707	9361	18	2850	265	79,378	308,084	110,165	4173	984,968
12	3017	175,212	1,339,353	60,638	451,189	22,305	30,408	4885	3,395,454	83,784	125,520	48,177	18,443	1,057,473
13	160,460	66,441	450,802	9208	121,862	13,498	98,052	1351	101	80,607	88,525	87,217	13,844	875,161
14	107,465	91,584	257,876	13,335	24,380	17,732	78,075	28,437	32	62,306	98,781	66,457	13,081	1,138,950
15	9922	331,671	336,782	15,199	223,190	116,870	126,129	20,773	1,388,382	95,373	90,099	80,185	17,760	1,069,642
16	486	82,207	227,280	–	105,070	48,757	68,953	3017	35,876	110,194	89,742	84,063	14,532	1,061,587
17	39,378	132,719	438,449	22,630	28,850	8616	65,730	5258	560	95,333	77,438	69,299	14,054	1,132,469
18	58,736	134,673	100,365	–	113,947	32,900	93,530	8966	364,920	113,757	92,716	89,759	8479	1,479,479
19	376,013	369,842	419,169	51,244	103,904	47,906	62,761	14,240	284,073	101,639	98,746	77,062	16,580	1,066,806
20	–	106,264	309,512	14,614	105,422	41,121	191,673	6771	183,508	133,865	105,447	68,194	16,905	1,065,458
21	5894	152,871	812,293	27,808	22,330	39,356	210,593	42,137	52,732	133,440	126,305	56,036	19,179	1,344,628
22	–	138,028	106,269	23,227	3053	48,486	15,365	15,156	3511	164,759	174,884	86,507	10,453	1,099,727
23	1,557,338	110,068	2,236,125	24,294	102,246	191,911	164,845	52,477	1585	124,657	202,905	48,903	12,294	1,161,751

<sup>a</sup> Omitted sectors presents the same coefficient at all regions. See coefficients at [Table A.5](#).

Table A.7  
Virtual water trade among regions (hm<sup>3</sup> of water withdrawal, 2009).

Region	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Water Trade Balance	
1	–	0.1	0.0	0.0	0.1	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	–7.3
2	0.2	–	1.3	0.8	7.1	27.6	1.4	0.3	1.0	1.7	0.2	0.2	1.2	0.4	0.8	0.3	0.4	0.1	0.4	7.2	0.1	0.3	108.6	–150.8	
3	0.0	0.8	–	0.0	0.1	0.9	0.1	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	–37.1
4	0.2	6.6	0.8	–	60.0	127.8	9.1	4.2	11.5	6.8	1.2	3.2	27.1	0.9	2.7	1.1	0.7	0.3	1.0	1.4	0.2	0.6	209.8	283.9	
5	0.2	7.3	1.0	4.5	–	98.0	7.1	1.7	5.1	7.5	0.9	0.8	4.0	1.7	3.1	1.4	1.3	0.3	1.4	1.3	0.4	1.2	266.4	–616.5	
6	0.5	18.1	2.8	8.5	149.6	–	17.3	3.0	8.8	18.8	3.1	2.5	9.4	5.9	8.6	3.7	3.5	0.9	4.4	3.2	1.7	4.0	635.1	–2460.9	
7	0.0	1.3	0.3	0.4	3.2	11.5	–	0.4	1.2	1.1	0.3	0.4	0.9	0.2	0.5	0.7	1.1	0.1	5.8	0.2	0.1	0.3	55.1	–212.5	
8	0.2	2.3	0.7	10.2	9.6	39.0	5.8	–	3.6	2.1	0.5	3.0	1.5	0.7	1.4	0.6	0.6	0.1	0.5	0.4	0.1	0.3	126.9	118.7	
9	0.4	9.4	0.6	14.2	47.1	89.4	8.8	2.0	–	7.1	0.7	1.8	3.2	1.1	2.8	1.6	1.0	0.2	1.2	1.2	0.3	1.0	231.1	203.4	
10	0.1	2.0	3.1	1.0	10.0	31.3	1.8	0.3	0.9	–	0.5	0.2	1.0	0.8	0.9	0.3	0.4	0.1	1.0	0.4	0.1	0.3	90.1	–123.7	
11	0.0	0.2	0.0	0.1	0.4	2.2	0.2	0.0	0.1	0.2	–	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1	8.8	–32.8	
12	0.1	1.6	0.2	2.3	5.3	28.8	5.3	2.1	2.7	1.4	0.2	–	1.5	0.4	1.7	0.8	0.4	0.1	0.6	0.3	0.2	0.3	119.1	118.3	
13	0.1	19.3	0.7	4.6	34.8	82.3	9.7	0.9	3.6	6.4	0.9	0.6	–	1.7	3.4	1.6	2.0	0.2	2.8	1.4	0.4	0.9	192.6	137.0	
14	0.0	1.0	0.1	0.4	3.8	16.2	0.9	0.2	0.4	2.2	0.3	0.1	0.5	–	0.3	0.2	0.8	0.0	0.2	0.2	0.1	0.2	58.5	–0.7	
15	0.1	3.7	0.4	4.6	19.4	62.9	4.8	1.0	14.8	3.6	1.3	2.1	2.2	1.0	–	3.3	0.9	0.9	2.4	1.2	0.7	0.6	172.8	120.6	
16	0.0	2.8	0.2	1.4	10.5	24.4	5.2	0.4	2.0	1.4	0.2	1.6	1.8	0.5	2.4	–	0.9	0.1	0.7	0.4	0.1	0.3	87.7	69.3	
17	0.1	1.7	0.4	1.0	7.0	33.7	5.9	0.3	1.2	3.3	0.7	0.3	1.8	3.8	1.0	0.4	–	0.2	0.7	1.0	0.7	1.1	104.6	80.8	
18	0.0	0.3	0.2	0.3	1.1	9.0	0.4	0.1	0.2	0.3	0.0	0.2	0.3	0.1	1.1	0.1	0.2	–	1.0	0.1	0.0	0.1	28.5	19.8	
19	0.1	2.2	0.4	2.6	13.5	64.5	5.7	0.5	2.5	3.6	0.4	1.8	4.6	0.7	4.4	2.0	2.3	2.5	–	1.6	0.5	0.7	179.6	190.6	
20	0.0	1.2	0.2	1.7	6.7	24.3	1.5	0.3	1.6	1.5	0.2	0.4	2.1	0.6	3.6	0.4	1.8	0.1	1.6	–	1.1	0.8	84.3	50.0	
21	0.1	1.6	0.2	0.7	6.1	28.8	1.7	0.2	0.5	1.4	0.4	0.1	0.5	0.3	0.4	0.1	1.7	0.1	0.5	2.0	–	0.6	60.0	74.5	
22	0.0	0.7	0.2	0.4	2.1	13.2	0.8	0.2	0.5	0.7	0.4	0.1	1.7	0.2	0.4	0.2	0.5	0.1	0.3	0.5	0.5	–	54.5	10.2	
23	6.5	228.0	28.1	133.6	635.9	2558.2	203.9	73.3	160.6	199.5	32.9	37.6	168.5	66.4	144.5	57.1	69.4	17.5	79.5	62.1	26.1	54.2	–	2165.6	

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