WATER DEMAND PROSPECTS IN BRAZIL: A SECTORAL EVALUATION USING AN INTER-REGIONAL CGE MODEL[1]

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ABSTRACT

This paper examined how regional expansion of irrigated agriculture affects the water demand in Brazil and used an inter-regional, bottom-up, dynamic model of general equilibrium calibrated for 2005 with projections for 2025. For the first time, a module able to integrate water use data prepared at the product level and calculated activity in million cubic meters (mm³ / year) was introduced. In the study, irrigated agriculture was separated from rainfed agriculture and had the productivity of irrigated agriculture distinguished from dryland activity regarding the main Brazilian crops. The database consisted of a series of studies and censuses, as well as continuous research that allowed the development of extensive data arrays for irrigated agriculture, industry, services, and household consumption. In Brazil, water availability represents about 12% of all the fresh water in the world, but the distribution of that water is not homogeneous across regions. The simulations aimed to expand the share of irrigated agricultural area in order to project demand of water use. The simulations were based on three different scenarios for the expansion of irrigated agriculture, as described in the National Water Resources Plan (PNRH) prepared in 2006 and intended for 2025. The water us in irrigated agriculture in Brazil represented about 90% of the total industrial us in the country. The results of the simulations suggest that the North would be more likely to expand the irrigated area, given the regional water availability, which provides a 0.021 ratio mm³ / hectare / year, unlike the Northeast region, identified as the most intensive area of water resources usage, with the ratio of 0.05 mm³/hectare/year for the three simulations. The results show that the use of water resources, especially in irrigated agriculture, is directly associated with water demands required in the cycle of the cultures and the way the irrigated area is distributed between cultures within the region. Such a distribution would promote the intensification in water resources us.

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1 INTRODUCTION

Brazil has about 12% of the world's fresh water, from which the Amazon region has 73% of water resources for only 4% of the country's population. On the other hand, the Paraná basin, with 32% of the Brazilian population, concentrates only 6% of the total hydric resources (Telles, 2013). In general, there occurs a high rate of hydric renewable availability per year un the country, but its distribution is not equal. The Brazilian territory has an extension of 8,5 million square kilometers and is divided into five geographic regions, with 26 Federation units and the Federal District (capital), with a total of 5,565 municipalities. The management of water resources needs is being debated constantly in order to avoid rationing situations and the misusage of resources. Thus, among the current 5,565 municipalities, about 55% will have a deficit in water supply in the upcoming years, 3,086 require some kind of investment for improvements in water supply, 2,506 municipalities need to expand the supply system and 472 municipalities need new water sources (ANA, 2010).

Irrigated agriculture requires an intensive us of water, especially the cultivation of rice. However, every crop has a specific production function with different water requirements (effective rainfall, soil moisture, handling, etc.), and crop productivity in irrigated agriculture becomes different from rainfed agriculture productivity (dryland), generating an incentive to farmers in the country and the formulation of guidelines to irrigated practice.

Brazil is a holder of approximately 12% of the whole planet's fresh water, but just over 5% of its agriculture is irrigated (ANA, 2013). In a large portion of the irrigated area in Brazil, traditional agriculture is practiced associated with a lack of technical guidance, and inadequate management causes waste of water us and reduces the benefits of irrigated agriculture. Another problem associated with irrigated agriculture is the poor stability of policies for the irrigation sector, which causes uncertainties, with changes in the conduction of policies for the irrigated agriculture, a sector of high potential for development. In Brazil, intervention from the public sector is justified by the need for credit policy, investments in logistics, adequacy of infrastructure, orientation programs for farmers, and others.

The study aims to evaluate the sectoral demand for water in the country and its impact on regional water resources given the creation of scenarios, especially for irrigated agriculture, based on the National Water Resources Plan (MMA, 2006). In Brazil, the data related to the concession of rights in the industry are incipient and much of the water us in irrigated agriculture comes from private sources and are not traded among economic agents. Therefore, the objective was to analyze water demand in an integrated inter-regional perspective and contribute to the literature in three distinct ways. First, by presenting the data of water us by activity and state in Brazil, generated from county-level information, especially for irrigated agriculture. Second, associating with the model the us of water in inter-regional details. Third, allowing, through the model features, comparisons between the projected demand for water and the potential regional irrigated area projection studies. In general, it is the first time this approach is carried out with the use of a GCE model and water flow demanded by year (m^3 / year). The preliminary results of the model are presented with predictions about the potential for expansion of regional irrigable area and comparisons in terms of watersheds.

2 LITERATURE

Water trade, price policies, restrictions and relocation of water and sustainable use in agriculture are some of the most varied policy formulation issues with the use of computable general equilibrium models in the world. Water is a subject widely discussed by researchers in the world, such as (Berrittella et al. 2005; Berrittella et al. 2007a; Letsoalo et al. 2007; Roe et al. 2005; Gomez et al. 2004; Diao. and Roe, 2003; Rosegrant et al. 2002).

The water supply restriction and / or water reallocation, as well as, modelling drought, are also analyzed by (Berritella et al. 2007b Calzadilla et al. 2008; Roson and Sartori, 2010; Seung et al. 2000; Diao and Nin-Pratt, 2005; Juana et al. 2011; Wittwer e Griffith, 2011). These studies can highlight the research conducted by Calzadilla et al. (2008) considering the difference between the water supply systems in agriculture: precipitation and irrigation indirectly had differentiated between rainfed activity and crops irrigated. The authors divided the land into land of upland and irrigated using its proportionate contribution to total production.

The studies that gave priority to sustainable water usage in agriculture as research focus can be found in (Calzadilla et al. 2010a; Lennox and Diukanova 2011). In the study of Calzadilla et al. (2010a), the authors defined sustainability of water when using the removal of groundwater on exploration in 2025, evaluated three scenarios involving the removal of water according to trends, a deteriorating scenario of water conditions around the world, and overexploitation of groundwater. In the study of Lennox and Dukanova (2011), the authors also simulated three different scenarios: the reduction of irrigated land (10%), the increased availability of labor and capital (10%), and the increase in prices of world agriculture (55%) shown negative impacts on intensive sector of water, a fall of production and a raise in prices.

Studies that analyzed climate change and its impacts on agriculture and water resources are shown in the studies by (You and Ringler, 2010; Calzadilla et al. 2010b; Calzadilla et al. 2013; Van der Mensbrugghe, 2010; Cakmak et al. 2009; Smajgl, 2009). In the Calzadilla et al.(2013) the studies evaluated the impacts of climate change on sub-Saharan Africa, specifically the agricultural sector. Van der Mensbrugghe (2010) used a prediction model to account for the impacts of climate change on water resources. Smajgl (2006) examined the impacts of climate change on the Great Barrier Reef region (GBR) in Australia, Cakmak et al. (2009) analyzed the irrigation management in Turkey, the impact on the economy as a price increase in agriculture, and climate change.

Basically, everyone highlights somehow the importance of agriculture within the context of water resources, demand, supply and trade.

3 WATER RESOURCES IN BRAZIL

Brazil has territorial dimensions of 8,512 million square kilometers, where in the contrasts of climate, population distribution and economic as well as social development are very large and make the country show the most varied scenarios. It has a privileged position in regard to most countries concerning the volume of water (about 12% of the world's fresh water). The availability of surface water in the country is of 91,000 m³/s (cubic meters per second) considering the sum of contributing streams to the point of a watercourse where all superficial runoff takes place (ANA, 2010).

Figure 1 illustrates how the Brazilian territory is divided in hydrographic regions, so it is possible to view its distribution in the country. In order to evaluate water availability, some concepts need to be clear, such as natural flow rate, which is the one that is originated in the basin without any human interference, a condition not always observed, and the flow of drought, which takes place when the river dilution capacity is reduced. The average natural flow rate parameter is not adequate in flow analysis studies since the discharge of the rivers have seasonal character and display multi-annual variability; on the other hand, critical periods of drought, in terms of water availability, are used to ensure a safety margin for planning and management activities. Therefore, in order to calculate the estimate of water availability of surface water in Brazil, an incremental flow of drought (95% stay with flow) was adopted (ANA, 2013).

Figura 1 – hydrographic regions in Brazil.
Source: ANA (2010).

The country has 200,000 micro watersheds scattered in 12 hydrographic regions, as illustrated in Figure 1. The major climate change in the country is reflected in the unequal distribution of available resources. In terms of water flow and population served, the Atlantic Northwest Oriental basin has water availability of less than 100 m³/s. At the Amazon basin availability achieves flow rates of 74,000 m³ /s. This goes to show the discrepancy in the supply of water in the country. The Amazon basin concentrates 81% of the availability of the Brazilian water resources distributed in 45% of the land area of the country. Therefore, 65% of all land area in the country has less than 20% of all available surface water resources (ANA, 2010).

Regions with lower flow and water availability are the ones found at the Parnaíba and Atlantic Northeast Western basins. Brazil has 3,607m³ of maximum volume stored in artificial reservoirs per inhabitant. This volume of water per capita has been used to evaluate the stock water level in a region which enables one to identify the degree of hydric vulnerability in order to meet water usages (ANA, 2013).

Further, Amazon Basin comprises an area of 2,2 million square kilometers in foreign territory, which contributes with additional 86,321 m³/s in terms of average flow. Similarly, the Uruguay basin is 37,000 square kilometers in foreign territory, contributing to 878 m³/s in terms of average flow. The Paraguay basin, with 118,000 km² area located in other countries, brings about other 595 m³/s in terms of average flow. Thus, if one takes into account the flows originating from a foreign country which pour into the country, the total water availability reaches values of 267,000 m³/s (8,427 cubic kilometers/year), which corresponds to 18% of the world availability (MMA, 2006b).

Table 1 shows water availability by watersheds in Brazil, the average flow rate in cubic meters per second (m³/s), the water availability in drought, the total area corresponding to the district of the basin and the urbanization rate.

Table 1 – Water Availability by Hydrographic region

Hydric Availability of the Districts				
Basin District	Average water flow m³/s	water availability / drought Q95.m³/s*	Total area	Urbanization rate
Amazônica	132,145	73,748	3,869,953 km²	67%
Tocantins-Araguaia	13,799	5,447	921,921 km²	74%
Atlântico Nordeste Ocidental	2,608	320	274,301 km²	57%
Parnaíba	767	379	333,056 km²	63%
Atlântico Nordeste Oriental	774	91	286,802 km²	76%
São Francisco	2,846	1,896	638,576 m²	74%
Atlântico Leste	1,484	305	388,160 km²	70%
Atlântico sudeste	3,162	1,109	214,629 km²	90%
Atlântico sul	4,055	647	187,522 km²	85%
Paraná	11,414	5,792	879,873 m²	68%
Uruguai	4,103	565	174,533 m²	91%
Paraguai	2,359	782	363,446 km²	8%
Brazil	179,516	91,071		

Source: Conjuntura Recursos Hídricos, ANA (2013).
Note: * Flow with permanence Q95 (m³/s): represents the flow that is equaled or exceeded 95% of the time (obtained based on the available number of flows).

A common situation regarding the flows is about the contribution of the districts that produce more or produce less water, which is to say there are districts where the variation of the specific flow varies little throughout the year, while in other basins such variation is relatively high. As an example, the basins of the semiarid region, where the flow rate can range up to more than 40 l/s (liter per second) per km² in the northwestern Amazon district, whereas the national average equals 21 l s.km² (ANA, 2005).

The water availability based on a guarantee of 95% is around 12,000 m³/s, or 22% of the average flow, excluding the contribution of water arising at the Amazon basin. Some anomalies were observed in the South and Southeast of the country in 2014, and exceptionally in the Southeast region, with periods presented 100 years drought periods, mainly at the basins of Parnaíba do Sul basin and Grande basin (ANA, 2015).

Groundwater availability in the main Brazilian aquifer systems represent a total renewable volume of around 20,473 m³/s and assuming that just 20% of these reserves are exploitable, the total value is 4,096.6 m³/s (ANA, 2013). Important cities like Belém (AM), São Luís (MA), Natal and Mossoró (RN), Recife (PE), Maceió (AL), and Ribeirão Preto (SP) are supplied, totally or partially, by wells. The authors also highlighted the fact that, possibly, the total number of wells built in Brazil by the year 2010 will be of 437,600, and in 2020, the forecast is of 545,600 (CARDOSO et al. 2008).

According to SIAGAS (Groundwater Information System), the number of registered wells in Brazil increased in 56.5% between 2008 and 2013 due to the inclusion of data belonging to the

States, especially those of Paraná and Maranhão. Thus, in January 2013, there would be 225,868 registered wells and 476,960 estimated wells in the country (ANA, 2013). Estimates of the Ministry of the Environment (MMA) noted that about 15.6% of households use only groundwater, and in some regions, that is the main water source.

According to the MMA (2006), the information about the quality of groundwater in the country are dispersed, being more concentrated in aquifers located nearby the capital. There is a lack of systematic studies on aquifers in a regional context and on the chemical and microbiological quality of the water. In the end, this can greatly increase the cost of treating water, as well as make costlier the search for new sources of funding, which affects society as whole.

4 IRRIGATED AGRICULTURE IN BRAZIL

The late nineteenth and early twentieth century were marked by the creation of a set of institutions devoted to climate issues, water availability and sanitation works against bad weather. In the Northeast (NE), specifically, a number of institutions have been created over the years in order to assess droughts and manage regional water resources, such as the Development Company of the São Francisco Valley (Codevasf), which, from 2002 on, began exercising its ruling also on the Parnaíba basin (MI, 2008).

Studies such as those of Vicente et al (2001) and Gasques et al. (2013) noted that the Brazilian production increased due the increase of productivity in crops and the usage of fertilizers and new techniques (such as irrigation). The growth of the planted area after the 80's increased cultivation of 13 major crops (corn, soybeans, cotton, rice, beans, wheat, etc.), which occupied an area of about 38 million hectares. In the 2013/2014 harvest, the area occupied was of about 57 million hectares. Another highlight is the agricultural productivity growth in Brazil, higher than 100% in the 2013/2014 harvest (3,393) when compared to the 1990/91 harvest (1,528) (Conab, 2015).

In Brazil, the irrigated area is of about 5,89% of the planted area when considering the 62 major temporary and permanent crops, and accounted for about 16% of total production MMA (2006a). Regarding irrigated agriculture, there are many works that approach the efficiency of irrigation, the improvement in techniques, and the challenges in the pursuit of efficiency (SILVA PAZ et al., 2000; COELHO, et al., 2005; CHRISTOFIDIS, 2006, MMA, 2006a; CHRISTOFIDIS, 2013).

The possibility of more annual harvest for some crops, different irrigation methods in different regions, climate, rainfall and other factors trigger regional differences in the country and hinders the projections and formulations of constant regional policies. The historical development of irrigated agriculture helps to understand these regional changes and guides research regionally. The Agricultural Census of 1985 reported a total of 1,959,810 hectares irrigated in the country and these areas increased to 3,121,648 hectares irrigated in the Census of 1995-96 and reached 4,545,532 hectares irrigated in the 2006 Census. In other words, an increase of 232% between 1985 and 2006. The National Waters Agency (ANA) released the water resources situation report in Brazil, which reported that an estimate of the irrigated areas was, in 2012, of around 5,8 million hectares (ANA, 2013), an increase of 46% between 2006 and 2012.

In Brazil, the largest source of data on agriculture and irrigated agriculture is the Agricultural Census. However, it is the most complete research on agriculture. Thus, the Agricultural Census of 2006 reported that about 329,000 establishments used some method of irrigation, or 6.3% of all agricultural establishments. This represents 15% of growth in irrigation compared to the Agricultural Census of 1995-96. Then, 74.8% of farmers stated using their own sources of water resources on their establishment, and 15.5% asserted using sources outside the establishment pumped by their own equipment (IBGE, 2009).

The national estimate of water use for irrigation in 2014 was 1,252.73 m³/s (ANA, 2015). The growth of the irrigated area is associated with the good performance that agribusiness shows in Brazilian economy, combined with private investment and new irrigation techniques. The country needs to expand for food production and can advance in terms of new areas for irrigation due to abundance of natural resources (FERGIE and SATZ, 2007; CONTINI, et.al. 2006; GASQUES, et.al. 2009). Table 2 shows the irrigated areas for major regions in Brazil between the last census and the estimate made by ANA (2013).

Table 2. Irrigated land by region.

	1985 (a)	**1995-96 (b)**	**2006 (c)**	**ANA 2012 (d)**
Northeast	366,826	751,891	1,007,657	1,238,734
North	43,242	83,023	109,582	205,123
Southeast	599,562	929,189	1,607,680	2,200,567
Midwest	63,218	260,953	581,801	861,015
South	886,962	1,096,592	1,238,812	1,291,634
Total	1,959,810	3,121,648	4,545,532	5,797,073

Created by the author
Source: a) IBGE (1991); b) IBGE (1998); c) IBGE (2009); d) ANA (2013).

Table 3 shows the regional growth of the irrigated area in percentual numbers. It is possible to observe that the region with the highest growth was the Midwest region, with a growth of 1,362% from 1985 to 2012. One of the highlights of this expansion is in the deployment of system production, driven by specific funding lines. As an example, in the state of Goiás, we can find the basins of São Francisco, Araguaia/Tocantins, and Paranaíba/Paraná.

Table 3. Percentage growth of irrigated area in Brazil compared to 1985 Census.

	1985	**1995-96**	**2006**	**2012 ANA**
Northeast	100	205%	275%	338%
North	100	192%	253%	474%
Southeast	100	155%	268%	367%
Midwest	100	413%	920%	1362%
South	100	124%	140%	146%

Created by the author
Source: a) IBGE (1991); b) IBGE (1998); c) IBGE (2009); d) ANA (2013).

The expansion of irrigated areas in Brazil remained in the year 2012 especially in the states of Alagoas, Bahia, Minas Gerais, São Paulo, Goiás. The state of Rio Grande do Sul contained a high irrigated land extension, according to previous censuses 779,534 hectares in 1985, 935,677 hectares in 1995, 997,108 hectares in 2006 and 1,027,473 hectares in 2012, with the growth rate over the census decreasing between the 2006 census and an estimated by ANA (2013) the state grew approximately by 30,000 hectares when compared with the states of the Midwest, which grew below the regional expansion carried out by the states of Goiás and Minas Gerais.

The Southeast and Midwest are the regions with the highest irrigated percentage in either permanent crops or temporary crops. This fact is associated with the climatic diversity that reaches these regions. The Midwest Region has semi-humid tropical climate with hot and rainy summers and cold and dry winters, hot and tropical climate region and no coastal region, drained by the Amazon and Tocantins-Araguaia basins.

Between the censuses of 1985 and 1995/96 the states as Amazonas and Pará reduced irrigated agricultural areas. Amazonas had a reduction of -51.04% (192 to 94 hectares), and Pará of -54.52% (9,099 to 4,138 hectares). The irrigated area growth in the country in regions such as Amapá (3,3729%) increased from 27 hectares to 9,107 hectares. From these, about 9,000 irrigated hectares belonged to Forestry and Extraction Plant. In terms of irrigated agriculture growth, the state of Alagoas had the largest expansion: between the censuses of 85 and 96 it increased 127,565 irrigated hectares (+ 488%), whereas the Rio Grande do Sul expanded to 161,731 irrigated hectares (+ 23%).

Between the censuses of 1995 and 2006 the irrigated agriculture in the state of São Paulo grew 368,078 hectares (99.56%), the highest growth observed in this period, followed by Minas Gerais 178,711 (77.05%), Espírito Santo 115,078 (153.59%) and Bahia 94,659 (60.81%). The reductions in irrigated hectares were noticed in the states of Tocantins 15,892 (-30.31%), Amapá 7,363 (-80.85%) and Paraíba 7259 (-14.59%). Figure 2 shows the total area irrigated grouped by Federation unit.

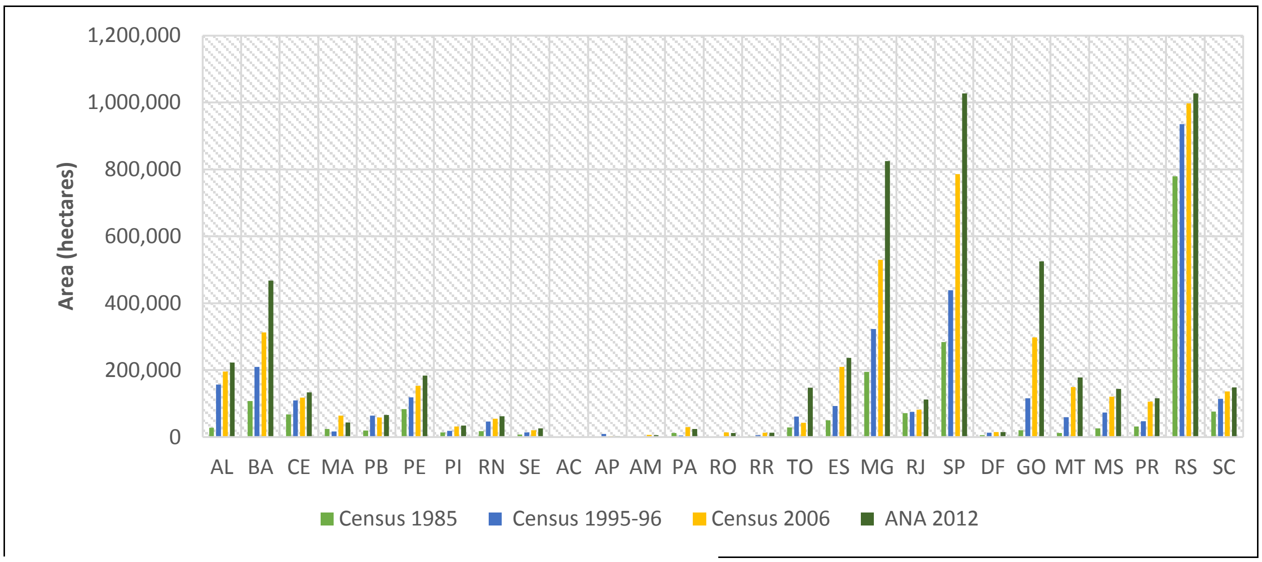

Figure 2. Evolution of irrigated areas by Brazilian state.
Created by the author
Source: a) IBGE (1991); b) IBGE (1998); c) IBGE (2009); d) ANA (2013).

Several studies show growth of grain production, the regional dynamics, the natural and technological conditions in the Midwest region, which is the region of the agricultural frontier in the country (Christofidis, 1999; Helfand and Rezende, 2000; ANA, 2003). Among the challenges for regional expansion of irrigated agriculture is the need to ensure water grants compatible with the demands of soils that are suitable for irrigation, which is becoming one of the biggest obstacles to the expansion of irrigated agriculture: among several, the reduction of water losses in the soil and inadequate management of irrigation (MMA, 2006a).

The irrigated area in 2014 was estimated at 6.11 million hectares (ANA, 2015). This development is highlighted by center pivot sprinkler irrigation methods, usage in which Minas

Gerais, Goiás, Bahia and São Paulo represent 80%, that is, the basins of Tocantins-Araguaia and San Francisco. The study also pointed out that about 96% of irrigated areas are private grounds.

The initial discussion of the development of irrigated agriculture is based on different methodologies that may not be strictly comparable. Studies aiming to assess the progress of regional agriculture in the country and help in understanding the geographic problems can promote and intensify production with reductions in environmental impacts. Although not strictly comparable, Figure 3 shows a relationship between the irrigated area described in studies of MMA (2011), with the planted areas disclosed in PAM (2006) and Agricultural Census (2006) for temporary crops and permanent crops.

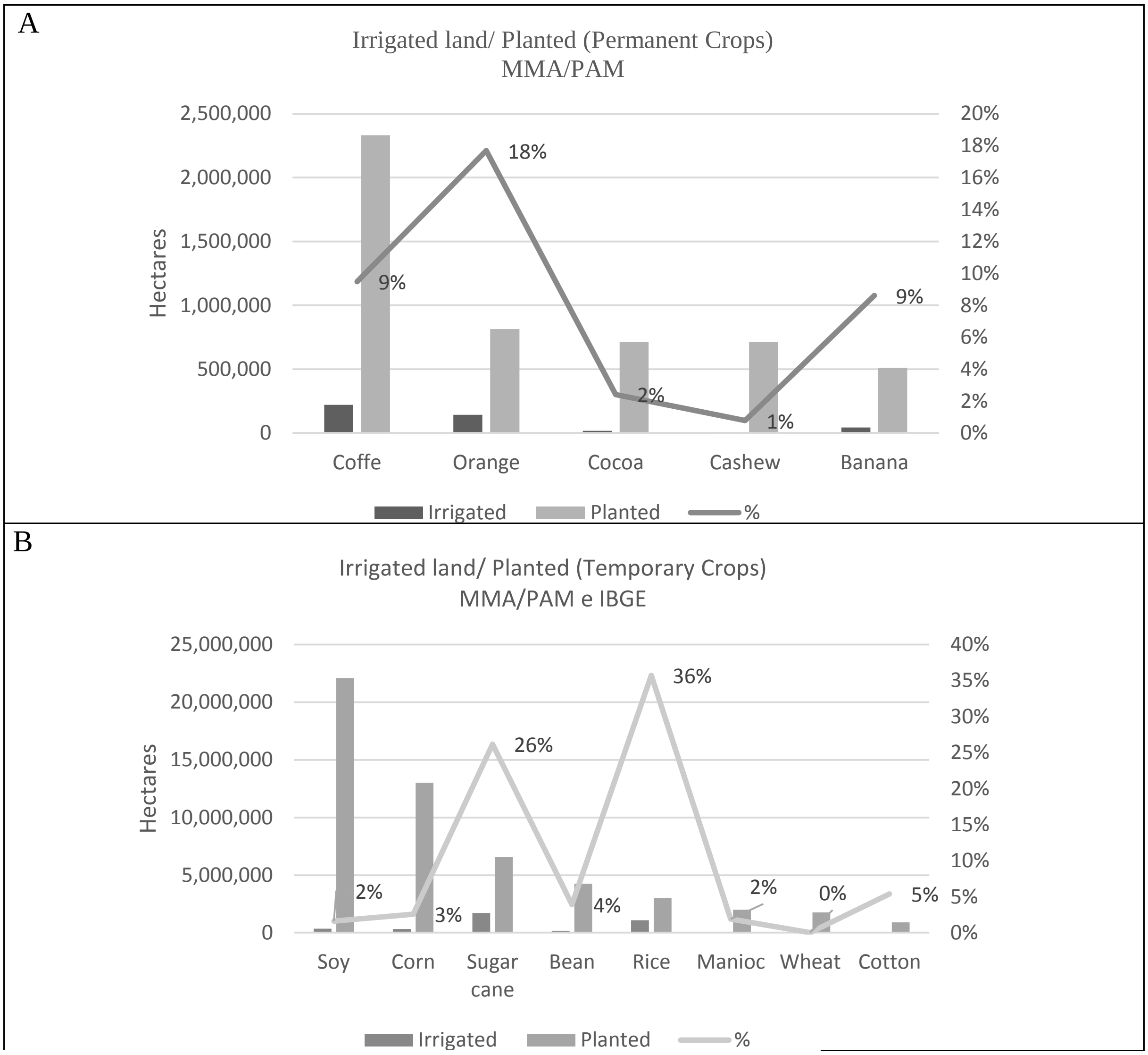

Figure 3. Percentage of irrigated areas over planted by type of crop.
Created by the author
Source: IBGE (2009), PAM (2007), MMA (2011).

It is possible to verify the importance of irrigation for the main Brazilian cultures as well as the generally incipient and divergent relationships among the crops, which can be regarded as differences in productivity, costs, and weather. Regional policies may encourage the irrigation for farmers or dispel it in the region. Regarding permanently irrigated crops, orange represented about 18% of the total growth in the country, and temporary farming we can verify this up to 36% for rice and 26% for sugar cane. It is emphasized that these percentages differ considerably among regions.

The potential for expansion of irrigated areas in Brazil is up to 61 million hectares compared to the current 5.8 million hectares. This means that the potential is about 10 times greater than the current usage, the greatest potential for expansion in the Midwest (MI, 2014). The study also revealed that the currently irrigated area, about 37% (2.2 million hectares), does not have the possibility of expanding the depletion of available water in their bowls. Other 44% (2.7 million hectares) of irrigation is in regions where there is significant expansion, but out of public intervention priority areas. The areas that warrant more significant public intervention and are aimed at sustainable regional development represent 19% of the irrigated area (1.1 Mha) and contain 36% of the additional capacity of irrigable area (27Mha) (MI, 2014).

5 TERM-BR MODEL

The study used the TERM-BR model, an inter-regional, multi-period, bottom up, general equilibrium model created for Brazil. It has been developed since 2001 in the Department of Economics, Management and Rural Sociology at ESALQ/USP by (FERREIRA FILHO e HORRIDGE, 2006; SANTOS e FERREIRA FILHO, 2007; FERREIRA FILHO e ROCHA, 2008; FACHINELLO e FERREIRA FILHO, 2010; FERREIRA FILHO et al., 2010; FERREIRA FILHO e MORAES, 2014; FERREIRA FILHO e HORRIDGE, 2014; FERREIRA FILHO et al., 2015).

TERM-BR is a typical CGE model in which each industry minimizes the production cost for a specific output level by optimizing labor, capital and materials. Production levels are chosen to meet the demands from different users, national industries, households, governments and other countries. The model captures the supply and demand for commodities, as well as the movement of such production to consumers considering several transportation modalities. The model includes an annual recursive dynamics and regional representation, which, in the simulations reported here, distinguished 15 Brazilian regions and included 36 commodities and industries and the demand of families, 10 types of households, 10 labor grades. The core database is based on the Brazilian input-output model of 2005.

5.1 The Water model

In Brazil there is no water trade among regions, and water resources reallocation policies are incipient due to the usage of one's own water resources in irrigated agriculture (wells, ponds, rivers, etc.) that run through farms and hinder the precise measurement of the information. In Brazil, the industrial requirements for the authorization for the use of water is filled only by a few industries.

For the historical simulation matrixes of planted areas were created (irrigated and rainfed), as well as matrixes of produced quantities, and of productivity by crop and region. Agricultural lands were divided into land-irrigated agriculture and dryland, and water use was calculated at the product and activity level in Million Cubic Meters of water per year (Mm^3 / year).

The matrix of water use was developed in the regional level and included 55 activities and 110 products to the 27 Brazilian states; this matrix was calibrated and adjusted to the model in 36 sectors plus household consumption, as well as 15 regions. The table 4 illustrates the matrix amount of water use for a specific region (Ri). The component (Q*i*, ...Q*n*) is the use of water in millions of cubic meters in each crop (*i*,...,*n*) into activities (For example: Agriculture). The total column represents the amount of water for a specific product (*i*) into activities. The sum of all lines is the total amount of water use in all products (*i*, ..., *n*) into activities. The same procedure was performed to all regions of Brazil.

Table 4. Regional matrix of water use by product and activities.

Water use (Q)	Agriculture	Livestock	Industries	Services	Households	Total
Agriculture (*i*,...*n*)	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	∑(Qi, ...,Qn) Ri
Livestock (*i*, ...*n*)	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	...
Industries(i,...n)	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	...
Services*(i, ...n)*	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	...
Households*(i)*	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	(Qi, ...Qn)Ri	...
Total	∑(Qi,...,Qn) Ri	∑(Qi,...,Qn) Ri	∑(Qi,...,Qn) Ri	∑(Qi,...,Qn) Ri	∑(Qi,...,Qn) Ri	∑(Q) Ri

Created by the author.

The matrix of water use was separated into non-agricultural activities (*noncrops*), household consumption (*house*), irrigated agriculture (*irrcrops*). Thus, the *noncrops* was updated by industrial activity (*xtot)*, the *house* was updated by real household consumption (*xhouse)* and *irrcrops* by *xlnd* (land use).

The growth of regional agricultural production depends on the areas of growth (irrigated, rainfed) and on the productivity of crops in each area. There is a direct relationship between the expansion of the area (irrigated, rainfed) and production growth as well as productivity gap. This relationship can be seen in the following equations:

$$K = SHRi.Ki + SHRn.Kn \tag{1}$$

K= Production/area; total area; K*i*= Production/area; irrigated land; K*n* = Production/area; rainfed land.

The equation (1) shows the relation between the parcels of irrigated land (SHR*i*) and non-irrigated land (SHR*n*) and the amount of land. In expanding the irrigated land (K*i*), the total land (K) is also expanded; the water use in irrigated agriculture regional increases with the expansion of irrigated area. The food supply grows in the irrigated area in relation to the rainfed area due to the productivity of the irrigated crop being higher than in dryland (rainfed). The following equations shown how the weighting occurs in these areas.

$$dK = Ki.dSHRi + Kn.dSHRn \tag{2}$$

$$dK = Ki.SHRi.shrig + Kn.SHRn.shrnig \tag{3}$$

From equation (3) it can be inferred that the change in aggregate agricultural productivity (dK) depends on the irrigated land and rainfed parcels (SHR*i* e SHR*n*), as well as on the variations of these parcels (*shrig* and *shrnig*). The areas projection is based on the matrix of area change for each crop into region between 2005 and 2014. This historical evolution of planted areas and quantities produced allows for regional projections according to the oscillations of harvests. If the productivity of the irrigated area K*i* > K*n*, then we have:

$$Kn = x.Ki \quad , \quad 0 < x < 1 \tag{4}$$

The variable x represents the higher productivity of the irrigated land compared to the rainfed land. Thus, by differentiating and making appropriate substitutions, we have in (5) the productivity elasticity for irrigated land, and in (6) how the production change varies the variation of the irrigated area.

$$\frac{dK^*}{dshrig} = \frac{SHRi\,(1-x)}{(1-x)SHRi+x} \tag{5}$$

$$\frac{dK}{dSHRi} = \frac{shrig\,(1-x)}{[(1-x)SHRi+x]}\left[1 - \frac{SHRi\,(1-x)}{(1-x)SHRi+x}\right] \tag{6}$$

Equations (5) and (6) describe the occurrence of weighting of output growth by productivity and growth of the irrigated area by the variation of the parcel of irrigated area. In this case, the variation of the parcel (*shrig*) is an endogenous element in the model, being determined by the economic policy adopted in the period. Changes in productivity are also treated endogenously via productivity matrix. The parcels of irrigated land (SHR*i*) are exogenous.

6 THE WATER DATABASE ELABORATION

The modeling of water use in Brazil required several steps to generate the water database. The database construction departs from basic information on technical coefficients of water use by MMA (2011) and Lisboa (2010) for 2007, by type of economic activity and region, together with information from other sources. In what follows we provide a summary of the database generation process, by type of water user.

6.1 Industry

Water used by industry is for intermediate use. The estimates followed the industrial classification, the type of technology, intermediate inputs, type of product, capacity, among other details. The process departs from the technical coefficients of water use by sector found in Lisboa (2010) and MMA (2011), for groups of industrial activity. These coefficients were calculated for year 2007, and their expansion to the sectoral level was done using information from the Annual Industry Survey (PIA) by (IBGE 2008a), for the same year of 2007. The original IBGE (2008a) database distinguishes about 3,000 products and 255 groups of activities that required aggregation and consolidation to the original water us database.

The elaboration of the water use matrix for the industry part of Brazilian economy followed four steps. Initially, the product classification was adapted to groups of activities based on the product classification of Prodlist (IBGE, 2011). Second, we proceeded to the adaptation (expansion) of the technical coefficients of water use by Lisboa (2010) and MMA (2011), which have 62 activities, to 255 activities, using the National Classification of Industrial Activities – CNAE, which allows for consistency between the two data sets. The third step involved the units of measurement in the product dimension. Out of the 255 groups of products, 92 required some kind of conversion in order to agree with the MMA (2011) technical coefficients classification, and

34 groups had no coefficient of water use. In this case, field interviews and other sources of information were used (interviews in companies, specific sites and others) that made possible the completion of the water use database for the industrial sector. Finally, the fourth stage involved the calculation of total water withdrawals, return and use, in m³/year, for 2,757 products arranged in 255 groups of activities. This database was further aggregated to 70 products and 27 activities, in order to comply with the Brazilian Input-output classification.

6.2 Agriculture

Regarding agriculture, we used directly the methodology described in MMA (2011), the same proposed by ONS (2005) to estimate the withdrawal, return and use of water in irrigation. The original database brings information by municipalities in Brazil in liters per second per hectares (l/s/ha). This municipal database allows the capturing of regional specificities in water use, which can vary sensibly even between close locations. The aggregation of this municipal database using municipal agricultural irrigated area by culture as weights allowed the construction of the national database of water use in agriculture by state and agricultural activity.

The data processing procedure is (l/s/ha) per cubic meters per year, consisting of three steps involving the Visual Studio 2012 software. The first step was developing a matrix that accumulated values in totals and averages for permanent crops and the maximum value for the temporary crops in cities, keeping the original formatting of the data in (l/s/ha). Secondly, the data of each crop in each municipality was summed up in order to obtain the state data. In the third step, these values were transformed in cubic meters (m³) per year and the procedure was performed for all cities, states, and all cultures available in the chosen database.

In the case of livestock, we used the methodology prescribed by ONS (2005) and information on herd size from the Brazilian Agricultural Census of 2006 (IBGE, 2009), wherein water demand is considered as for animal use only. The planted area data for the year 2006 were taken from the Agricultural Census 2006 IBGE (2009) and PAM (2006). There was also produced a historical matrix of area change and quantities produced in the crops / states with data from PAM (2005-2014).

The technological pattern per unit of area results in a level of productivity. The production technical coefficients define the quantities of inputs used per hectare in each crop through of a specific production function for the crops. Thus, an extensive literature survey of experiments conducted in Brazil was held. The authors considered the technical and regional specificities of each culture in order to identify increased productivity under irrigation at the expense of rainfed crops. Based on the work it was possible to develop the productivity matrix for crop/state (DE SOUZA et al. 2010; DE MELO SOUZA, et al. 2013; KONRAD, 2002; BARROS, 2003; FAGERIA, et al. 1995; SANTOS e RABELO, 2004; RESENDE, 1999; AMORIM, et al., 2011; REZENDE e ANDRADE JÚNIOR, 2008; TOSTA e JÚNIOR, 2014; VESCOVE, 2008; LOPES, 2006; MARQUES, FRIZZONE e PERES., 2004; MARQUES e COELHO, 2013; SOUZA, et al. 2014; ROCHA, et al.,2010; DE SOUZA, et al., 2009, GAVA et al. 2011; KOURI et al. 2005).

For the historical update of the irrigated area between 2006 and 2012, the 2006 Census was used (IBGE, 2009) as well as data from ANA (2013). The total variation between 2006 and 2012 by region was calculated. We used the irrigated percentage of 2006 and adopted the same percentage for 2012. The hypothesis was that there was no percentage change in the allocation of irrigated land between crops in the regions.

6.3 Households, trade and services sector

The estimates of water use and return by households used a methodology adapted from ONS (2003) and ONS (2005), as well as population data from the Brazilian Demographic Census of 2007 (IBGE, 2007) and the National Survey on Basic Sanitation 2008 (PNSB, 2010). The flow chart below illustrates the steps followed for the calculation.

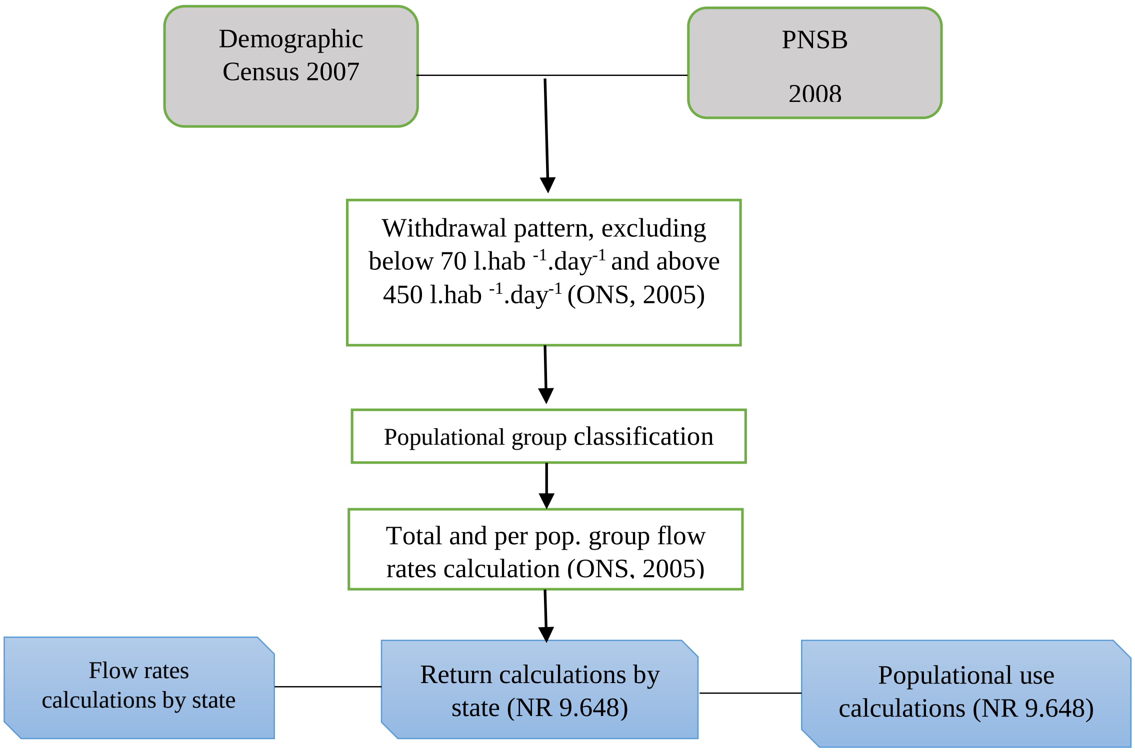

Figure 4. Flow chart of the methodology used for household water use calculations.
Created by the author.

Regarding the service sector, we used the hypothesis that these activities, composed mostly by human activity, use the equivalent of the per capita regional use of water in liters per habitant per day for the total number of persons occupied in each activity in each state during working hours. Sectoral allocation was performed using the share of workers in each sector obtained from the National Households Survey – PNAD from 2007 (IBGE 2008b).

Table 5. Water use in Brazil, by sector (aggregated). Million m3/year (Mm³/year) 2005.

	Withdrawal		Return		Use	
	Mm³	Share	Mm³	Share	Mm³	Share
1 Agriculture	285,498.8	0.82	79,471.5	0.66	206,027.3	0.90
2 Livestock	4,019.7	0.01	803.9	0.01	3,215.7	0.01
3 Mining	1,725.1	0.00	399.4	0.00	1,325.6	0.01
4 Process. Food	6,207.3	0.02	3,125.7	0.03	3,081.6	0.01
5 Manufacturing	49,670.0	0.14	35,331.9	0.29	14,338.1	0.06
6 Services	2,337.2	0.01	1,869.8	0.02	467.4	0.00
Total	349,458.0	1	121,002.2	1	228,455.7	1

author´s elaboration.

As can be seen, the use of water in irrigated agriculture answered for 90% of the total sectorial use in Brazil, and it justifies the interest in evaluating the possibilities for expansion of irrigated agriculture and the impact on regional water resources. The final water database for the Brazilian economy has data concerning 110 products and 55 activities, and 5 present an aggregated version.

6.4 Scenarios

The construction of the scenarios include distinct situations for the analysis of future demand of sectoral water use in Brazil, especially in irrigated agriculture, livestock, industry, household consumption, characterized in PNRH by MMA (2006) together with the study of agriculture Territorial Analysis Irrigated by (MI, 2014). There are three scenarios described in the plan: “Water for all”; “Water for some” and “Water for a few” (MMA, 2006).

The first scenario, "water for all", includes a world that grows in an integrated and continuous fashion. Brazil has a development model that goes towards reducing poverty and social inequalities, increasing circulation of consumable goods in the South American continent and fastest access to Asian countries, the Australian continent and the US west coast. With 209 million people, Brazil has a higher growth than the global growth, exports increase given the opportunities offered by global growth, and domestic consumption also expands with increasing income and employment generation. Poverty indicators fall to 33% observed in 2010 to 20%, life expectancy is now 78 years; infant mortality rate reduces illiteracy to less than 7% and GDP *per capita* growth. Brazil has a Human Development Index (HDI) of 0.910, but it is still an emerging country. From an environmental standpoint, deforestation rates fall and a strong scientific, technological and innovational development sustain economic dynamism.

Agriculture expands, mainly in the Midwest (Mato Grosso do Sul, Mato Grosso, Goiás) and the Northeast (Bahia, Pernambuco, Rio Grande do Norte and Maranhão) and the North (Rondonia, Tocantins and Pará) with relevance of the production of food such as cereal and fruits. Cultivation of sugarcane for the production of fuel and cotton for the textile industry is also expanded. The disputes over water resources increase in the South and Southeast. Irrigated agriculture grows at an average annual rate of 170 thousand hectares (area). The Production increases are greater than 58% due to higher crop yields and the strong expansion of livestock, with an emphasis on the Midwest.

In the second scenario, "water for some," Brazil and the world are governed by strong exclusionary dynamism, there being a strong impact on water resources and rising rates of inequality and degradation of water resources with little regulation and supervision in the use of water. Moderate economic expansion internationally, with dynamism concentration in developed countries, technological innovation keeps increasing, but the exclusion of certain markets induces the global average growth. Brazil goes ahead with moderate growth and economic dynamism concentrated in the South and Southeast of the country and reduction of state presence to the regulatory action. Brazil, with an HDI of 0.880, is an emerging country.

Agriculture expanded by the Midwest (Mato Grosso, Mato Grosso do Sul, Goias) and the North (Rondonia, Tocantins and Pará) with increase in the production of food such as grains, fruits, especially grapes, under the influence of growth in global demand, particularly China, expansion of sugarcane plantations for the production of fuel and cotton for the textile industry. The average expansion of irrigated area is of 120 hectares. Agriculture’s focus is in exporting, livestock confirms the migration from the South and Southeast to the Midwest and to the North, excluding small farmers, credit marginalization, increased runoff and siltation of watercourses. In industry, large water users follow its expansion to focus on exports. The demands for industrial water stand out in the regions of Paraná and Southeast Atlantic.

In the third scenario, "water for few", Brazil has a small growth of infrastructure for economic activities, there is no significant expansion of energy supply, investments in water resources protection are small, inefficient and bureaucratic state management. The world is highly unstable and with low economic growth (only 1%), the world is suffering the effects of internal political shocks in China, India and Russia, the research networks and technological development lose incentives.

Brazil is stagnated by several factors, among them the lack of a dominant political project, with a population of 28 million inhabitants. The country has a GDP per capita similar to that of 2005, a life expectancy of 74 years, HDI 0.830. The irrigated agriculture grows slowly at an annual average rate of 70 hectares of irrigated area, with little innovative technologies. The largest expansions occur in the watersheds Amazon, Tocantins-Araguaia, Parnaíba and Western Northeast basins, and the other regions have modest expansions.

The most significant irrigated area is in the watersheds of Parana, South Atlantic and Uruguay, and less significant in the watersheds of Paraguai, Parnaíba and Atlantic Western Northeast. Livestock is concentrated in the traditional poles in the South, Southeast and Midwest of the country. The lack of an adequate agricultural policy causes the uncontrolled livestock feed to create degradation in the major biomes, increasing illegal deforestation and environmental losses, vegetable extraction growing in the North. The production of sugarcane for fuel and cotton for the textile industry increases. Mineral extraction loses pace of growth in face of falling global demand and substitution of natural resources.

Despite the low economic productivity, water appropriation increases, the expansion of the electricity sector reduces, few projects are constituted. The development keeps up with the growth of cities in the interior of the South and Southeast states, and especially in the Midwest of the country. This expansion is done without adequate infrastructure, compromising quality of the water in these regions.

As the scenarios described in the PNRH plan include the growth of the total irrigated area in Brazil, regionalization of this information is necessary. Therefore, we considered the percentage of regional irrigable area described by (MI, 2014). Thus, the synthesis of the three simulated scenarios constitutes:

1) Water for all: land areas with high and medium suitability of infrastructure and development and for the installation of irrigation systems, annual growth of 170,000 hectares;
2) Water for some: land areas with high suitability to infrastructure and development for the installation of irrigation systems, annual growth of 120 000 hectares;
3) Water for few: land areas with high suitability to infrastructure and development for the installation of irrigation systems, annual growth of 70 thousand hectares.

Lands with high irrigation potential are lands described in terms of areas with maximum theoretical potential in ideal soil conditions and infrastructure; therefore, it refers to the potential of the region considering the watersheds (MI, 2014).

6.5 Closure of the Model

The PNRH considered the period up until 2020. However, with the availability of macroeconomic data (GDP, Private Consumption, investments, etc.) and planted and irrigated land, it was possible to draw up an economic closure with a longer time horizon than that described in the plan. The new time horizon considered was from 2005 until 2025. The historical data about irrigated land was updated with information until 2012, planted area, and macroeconomic variables until 2014.

The simulation started in 2015 and the choice of exogenous variables aimed at the identification of the possible demand for the water consuming sector in 2020 and 2025 in face of the regional irrigated area in the country. The closure adopted long-term dynamics with a system of equations for the three scenarios. We considered as exogenous macroeconomic variables the real government consumption, real GDP, real household consumption, exports and real investment. The PNRH scenarios describe different percentage of GDP growth. However, we chose to adopt GDP growth at 2.5% from 2015 to check the isolated effect of regional expansion of irrigated area as a policy shock in the three scenarios. Population growth increases according to the projections of IBGE.

In the closure of policy, the irrigated portion, by crops and region, is exogenous. For regional irrigated area to grow at a rate able to reach the goal in each scenario, the irrigated area should grow at an annual rate consistent with the prediction of detached scenarios in the PNRH. The system of equations that was adopted considered, in addition to the growth in irrigated area, the productivity of the largest irrigated crop as bigger than in the rainfed area, and regional productivity gains can be identified.

7 FINAL REMARKS

In the analysis and assessment of the results, two time periods, those of 2020 and 2025, were considered. Since in face of the updates brought about to the study the year 2020 would be relatively close and could not necessarily reflect the research objective of simulating and evaluatig the demand on water use and its impacts on water resources in Brazil.

In macroeconomic terms, change in water use change 2005-2020 and 2005-2025 is greater in scenario 1 (CEN 1), "water for all". This scenario considers domestic and external economic growth, whose increase in exports comes from growth for irrigated agriculture with environmental and structural sustainability. Exports also increase more in this scenario as well as the average price and the actual spending in face of GDP. The main results of the simulations (CEN 1, CEN 2 and CEN 3) are shown in Table 6.

Table 6. Model results, variation from the baseline (CEN 1, CEN 2, CEN 3).

Description	CEN 1		CEN 2		CEN 3	
	2020	2025	2020	2025	2020	2025
Average price shift export demand (% change)	0.004	0.015	0.003	0,010	0.002	0.007
Commodity exports (% change)	0.351	0.784	0.249	0,526	0.157	0.321
Total (national) water use, Mm3/year (change)	42,326	106,698	29,961	69,377	19,033	42,473
Used Land Area (Millions of hectares)	0.002	0.011	0.001	0,006	0.001	0.004
Total (national) water use (%change)	14.89	36.51	10.57	23,90	6.71	14.63
Real expenditure GDP (% change)	0.063	0.173	0.045	0,117	0.029	0.073

Model results.

The expansion of water use in CEN 1 would be higher than in the second and third scenarios, which, in fact, would require major investments in infrastructure and technology and improved management of water resources. These results are detailed and compared with the growth of the regional area.

The intended total irrigated area according to the PNRH was confronted with the results of the baseline simulation. The difference in value refers to an update of the historical basis not observed when the plan was defined. The PNRH (1, 2 and 3) describes the irrigated area in million hectares (Mha) by region based on the annual area projected by (MMA, 2006), and this area was redistributed between the regions according to the regional irrigated area observed in 2006 by the Census (IBGE, 2009). The irrigated land simulations for the three scenarios (CEN 1, CEN2 and CEN3) are shown in table 7.

Table 7. Irrigated area in (Mha) for the (PNRH) and model results (baseline).

Regiões	PNRH 1	Simulation (CEN1)		PNRH 2	Simulation (CEN 2)		PNRH 3	Simulation (CEN 3)	
	2020	2020	2025	2020	2020	2025	2020	2020	2025
Rondonia	0.085	0.028	0.055	0.091	0.028	0.057	0.059	0.015	0.016
Amazon	0.488	0.268	1.1	0.247	0.205	0.642	0.15	0.076	0.084
ParaToc	0.257	0.572	0.964	0.142	0.473	0.661	0.107	0.369	0.4
MarPiaui	0.167	0.114	0.16	0.099	0.096	0.113	0.084	0.083	0.085
PernAlag	0.686	0.321	0.324	0.678	0.319	0.321	0.674	0.318	0.319
Bahia	0.36	0.633	0.748	0.326	0.613	0.701	0.29	0.554	0.573
RestNE	0.284	0.257	0.27	0.274	0.254	0.264	0.266	0.248	0.251
MinasG	0.635	1.07	1.23	0.554	1.019	1.124	0.499	0.93	0.937
RioJEspS	0.218	0.363	0.337	0.209	0.357	0.326	0.208	0.357	0.325
SaoPaulo	0.964	1.11	1.18	0.946	1.098	1.163	0.884	1.038	1.039
Parana	0.245	0.136	0.169	0.2	0.127	0.147	0.171	0.11	0.11
SCatRioS	1.248	1.22	1.26	1.228	1.217	1.249	1.175	1.173	1.162
MtGrSul	0.333	0.288	0.417	0.326	0.285	0.41	0.244	0.209	0.221
MtGrosso	0.587	0.283	0.49	0.533	0.274	0.459	0.361	0.167	0.17
Central	0.473	0.927	1.22	0.431	0.898	1.147	0.359	0.759	0.818
Total	**7.029**	**7.58**	**9.92**	**6.283**	**7.264**	**8.785**	**5.531**	**6.407**	**6.511**

Model Results.

The regional difference between simulated scenarios (CEN1, CEN 2, CEN3) and projections of PNRH (PNRH1, PNRH2, PNRH3) occur due to two factors; a) The historical update growth of regional irrigated agriculture between 2006-2012 growing more than described in PNRH1, surpassing the 200,000 (219,748) hectares per year, especially in the Tocantins (243, 78%), Goiás (+ 76.24%) and Minas Gerais (+ 56.64%) states and; b) The growth simulation for each scenario has been drawn up according to the percentage of the potential irrigable area in each state by MI (2014). Therefore, a region may have a potentially high irrigable area; however, in the historical period it might have had its area reduced and/or have raised its irrigated area above the regional irrigable potential.

When we evaluating the irrigated area in Brazil, the numbers do not necessarily reflect the size of the country and the opportunities for regional expansion. Therefore, in order to understand and verify the magnitude of the simulation proposals regarding the regional territory without assessing infrastructure, regional economic and social development, it was decided it would be necessary to compare the percentage of irrigated area in relation to the regional territorial extension. Thus, Table 8 shows the area in 2012 (observed) and the Mha simulations for cumulative policy deviation to the irrigated area (CEN1, CEN2, CEN 3) in relation to regional territorial extension.

Therefore, it is clear that the irrigated land in the three scenarios is less than 1% of the Brazilian territory. As the result of the simulations, the largest irrigated lands occur in the Central area (1.32%, 1.08% and 0.65%), followed by São Paulo (0.63%, 0.61% and 0.37%), as a result of the percentage shock occurring in the irrigated regional parcel in regions of great areas irrigated in their base, with a high area expansion potential.

The region of PernAlag (Pernambuco and Alagoas) had in 2012 a total of 3.23% irrigated area observed in regards to the regional land extension. However, the simulations shows that this irrigated area would not have a high expansion in 2025. The same applies to ScatRioS (Santa Catarina and Rio Grande do Sul), which is a strong region in rice production but has low potential expansion in irrigated areas. These results and others are shown in Table 8.

Table 8. Regional territorial extension regional in Brazil, irrigated land in 2012 and policy deviation related to CEN1, CEN2 e CEN3 (% to territorial extension in 2025).

Regions	Territorial Extension (1000 km²)	% irrigated land 2012	% CEN1 / Territorial Extension	% CEN2 / Territorial Extension	% CEN3 / Territorial Extension
1 Rondonia	237.5	0.05%	0.20%	0.21%	0.13%
2 Amazon	2090.2	0.01%	**0.66%**	**0.35%**	**0.23%**
3 ParaToc	1525.2	0.11%	0.44%	0.20%	0.12%
4 MarPiaui	583.5	0.13%	0.15%	0.05%	0.03%
5 PernAlag	126.0	3.23%	0.05%	0.02%	0.02%
6 Bahia	564.6	0.83%	0.35%	0.26%	0.15%
7 RestNE	279.9	1.02%	0.08%	0.05%	0.03%
8 MinasG	587.5	1.40%	0.56%	0.36%	0.21%
9 RioJEspS	89.6	3.89%	0.15%	0.01%	0.01%
10 SaoPaulo	248.2	4.14%	**0.62%**	**0.55%**	**0.33%**
11 Parana	199.3	0.58%	0.33%	0.21%	0.12%
12 SCatRioS	377.0	3.12%	0.29%	0.25%	0.15%
13 MtGrSul	357.1	0.50%	**0.63%**	**0.61%**	**0.37%**
14 MtGrosso	903.3	0.16%	0.42%	0.37%	0.23%
15 Central	345.8	1.56%	**1.32%**	**1.08%**	**0.65%**
Brazil	**8514.7**	**0.68%**	**0.49%**	**0.31%**	**0.19%**

Model Results

In the irrigated area simulations (hectares) it was considered that the land proportion of each irrigated culture was kept along the years. Thus, expanding regional irrigated area will be more intense for the important regional crops. The effects of CEN 1 occur in the Amazon region (Amazonas, Acre, Roraima and Amapá), which are states located in North of Brazil whose main activity is associated with extraction plants such as palm, assai and rubber tree. However, for this expansion to take place, investments in infrastructure, technology and improved management of resources had to be done, because the regional water availability by itself is not a sufficient condition for such expansions to occur.

In CEN 1 (water for all) the growth of foods such as fruits and cereals expand in the Bahia and Central regions (Goiás and Distrito Federal), crops such as wheat and other cereals expand in MinasG (Minas Gerais), cotton expands in MTGrosso (Mato Grosso) and Bahia, the sugarcane expands in MinasG, Mato Grosso do Sul (MtGrSul) and Central. In general, the regions have been developing themselves over the past decades with irrigated agriculture and have the potential to expand its irrigated agriculture. This result of the cumulative policy deviation to the irrigated area (Mha) by crops and state in 2025 are shown in Annex A, Table A.1.

The simulation for CEN 2 (water for some) has a regional moderate growth with exclusive dynamism and strong impact on water resources. Irrigated agriculture related to rice grows more in the regions of ParaToc (Pará and Tocantins) and SCatRioS (Santa Catarina and Rio Grande do Sul), the coffee expands in Rondonia, other farming products and citrus fruits would expand in the state of São Paulo (SaoPaulo), sugarcane expands in Minas Gerais, Sao Paulo, Mato Grosso do Sul and Central. The results for the cumulative difference by crops and region for the year 2025 in Mha are in Annex B, Table B.1.

In the simulation for the CEN3 (water for few) the country has low economic and infrastructure growth, the emphasis is irrigated agriculture, especially at the Amazon basin, the regions expands crops and activities that were considered dominant in 2005. Therefore, the main results happen in the Amazon region, for crops such as palm, rubber tree and assai. States such as Para, Tocantins and Mato Grosso would expand soybeans, while in the states of Bahia, Minas Gerais, São Paulo, Mato Grosso do Sul and Goiás the expansion would occur in sugarcane. All accumulated results for 2025 in CEN3 are in Annex C, Table C3.

The cumulative percentage of water use in the three simulations for each region is shown in Table 9. The Amazon region has the highest percentage and would show greater conformity (980%) to CEN1 results in 2025, which is consistent with the fastest growing percentage of the irrigated area region.

Table 9. The cumulative percent change for water use (policy deviation).

% water use by state	CEN 1		CEN 2		CEN 3	
xwater_u(D)	2020	2025	2020	2025	2020	2025
1 Rondonia	40.12	102.52	42.77	112.27	29.90	71.32
2 Amazon	230.42	984.78	148.64	514.84	110.38	337.34
3 ParaToc	61.08	142.34	30.14	62.98	19.27	38.51
4 MarPiaui	39.60	84.79	15.28	29.78	9.47	17.97
5 PernAlag	0.90	1.64	0.46	0.84	0.27	0.49
6 Bahia	16.49	32.24	12.20	23.48	7.39	13.93
7 RestNE	3.74	6.89	2.79	5.14	1.65	3.01
8 MinasG	15.78	30.68	10.29	19.59	6.21	11.60
9 RioJEspS	2.11	3.82	0.16	0.28	0.09	0.17
10 SaoPaulo	5.57	10.19	5.02	9.22	2.99	5.43
11 Parana	8.60	16.51	5.70	10.67	3.50	6.37
12 SCatRioS	4.66	8.61	4.11	7.59	2.43	4.46
13 MtGrSul	41.65	90.25	40.62	87.75	26.25	53.66
14 MtGrosso	65.63	158.07	60.65	143.75	41.15	89.99
15 Central	26.03	53.00	21.72	43.53	13.49	26.15

Model results.

The irrigated land expansions in MI (2014) occur in regions where there is a greater regional water potential, such as the Amazon basin and the Tocantins-Araguaia basin. The problem of water use is associated with regional water availability, specifically, the management of this resource and structural and social conditions that the regions offer, as well as skilled labor in irrigated agriculture in order to provide efficient usage on irrigation techniques. Cumulative growth of national water use level advances over the years for CEN1, CEN2, CEN3. This main increase is driven by irrigated agriculture in the country, and water intensive use in rice and sugarcane (Figure 5).

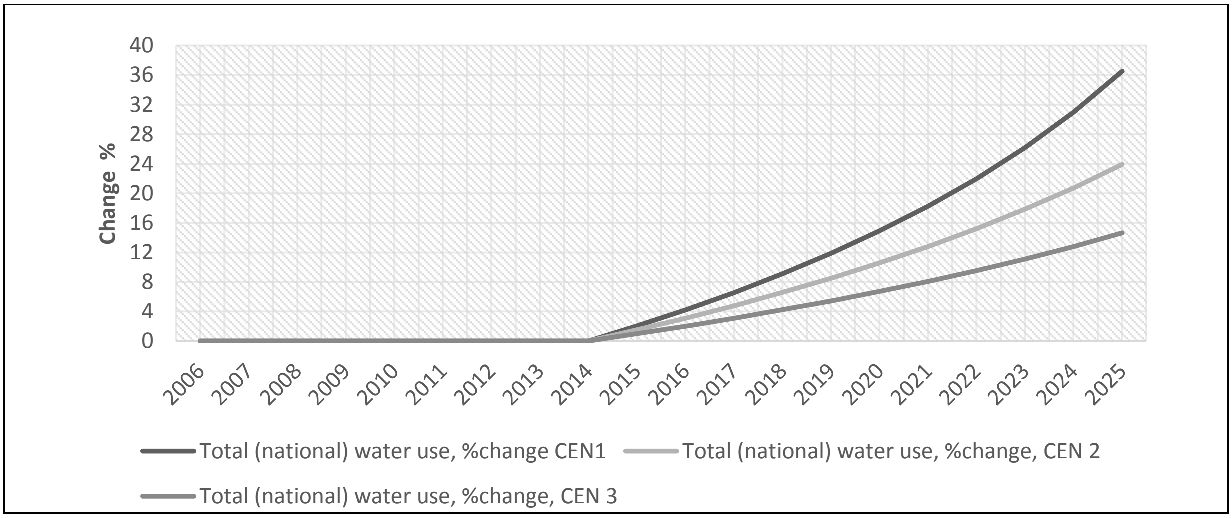

Figure 5. National water use for the simulations (% change).
Model results.

The national percentage change of water use in CEN 1 would reach 36% regarding its base, being the largest cumulative change for 2025 between simulations as the result of an expansionist, technology-oriented policy, but mainly derived of the shock in the regional expansion portion of regional irrigated agriculture. The difference between CEN1 and CEN3 is almost 22%, i.e. there is a difference of over 100 000 hectares per year between 2015 and 2025. In CEN 3 Brazil would present little growth of economic activities, urban infrastructure and logistics becoming stagnant, the protection water resources investment being small within an inefficient and bureaucratic state. However, irrigated agriculture in the country would continue to grow at lower rates.

Non-traditional areas in irrigated agriculture (e.g. Amazon) (IBGE, 1987; IBGE, 1997; IBGE, 2009; ANA, 2013) with small irrigated areas (hectares) but with high growth potential due to regional water availability (ANA, 2010; MI, 2014) should be evaluated not just in percentage terms, as a high percentage applied to small areas does not necessarily result in high water consumption. Another item to consider is that the predominant irrigated crops in the region can in turn, require a greater volume of water use throughout the crop cycle in the region over another.

Industrial activity is versatile and requires constant investment and technology changes to advance in the Brazilian production. The country has a large and varied industrial park that produces consumption goods and technology, currently mainly concentrated in the South and Southeast and advancing to the Northeast of the country. In fact, the introduction of modern water systems in the industry is the result of investments, public policies and targeted legislation that forces the improvement of the production process. Therefore, Table 10 shows the model result to water use accumulated in mm³ for 2020 and 2025 per user in Brazil.

Table 10. Model results to Mm³ of water use in Brazil in 2020 and 2025 (Police deviation).

Mm³ water use	CEN 1		CEN 2		CEN 3	
Delxwater_d	2020	2025	2020	2025	2020	2025
1 Rice	**10,399.27**	**24,068.65**	**6,367.41**	**13,360.46**	**3,959.29**	**8,064.95**
2 Corn	1,498.45	3,519.21	1,089.94	2,452.20	698.52	1,500.40
3 Wheat and others	37.71	79.08	25.50	52.51	15.47	31.20
4 Sugarcane	**15,884.53**	**34,360.20**	**12,549.28**	**26,931.46**	**7,795.24**	**16,193.01**
5 Soy	1,827.32	4,167.34	1,421.54	3,157.03	914.25	1,932.11
6 Farming	4,744.55	10,427.48	3,265.34	6,873,42	2,019.58	4,141.35
7 Manioc	765.09	2,041.24	357.56	919.61	233.41	574.22
8 Tabacco Leaf	1.72	4.75	1.28	3.16	0.80	1.95
9 Cotton	484.33	1,108.42	407.08	923.97	264.59	568.07
10 Citrus Fruits	753.59	1,836.11	543.62	1,213.32	340.13	735.69
11 Coffee	1,041.71	2,216.09	748.43	1,620.35	464.68	977.25
12 Forestry	**4,872.34**	**22,820.72**	**3,197.00**	**11,946.70**	**2,334.66**	**7,797.04**
13 Catlle and other	5.33	14.60	3.85	10.04	2.44	6.23
14 Milk	0.00	0.00	0.00	0.00	0.00	0.00
15 Pigs and Poultry	0.53	1.58	0.38	1.07	0.24	0.66
16 Mining	-2.68	-8.78	-1.92	-5.94	-1.22	-3.69
17 Meat	0.07	0.20	0.05	0.13	0.03	0.08
18 Oils	0.28	0.80	0.20	0.54	0.13	0.33
19 Dairy	5.50	15.31	3.91	10.40	2.46	6.41
20 Rice industry	0.00	0.01	0.00	0.01	0.00	0.00
21 Sugarcane industry	6.76	19.44	4.84	13.30	3.03	8.16
22 Coffee industry	0.00	0.00	0.00	0.00	0.00	0.00
23 Other food industries	0.47	1.29	0.33	0.87	0.21	0.53
24 Textile	0.38	0.62	0.58	1.79	0.44	1.22
25 Paper industry	-1.20	-0.78	-0.92	-1.19	-0.47	-0.38
26 Gasoline	0.00	0.00	0.00	0.00	0.00	0.00
27 Fuel	0.00	0.00	0.00	0.00	0.00	0.00
28 Alcohol	0.13	0.35	0.11	0.32	0.07	0.19
29 Oil and gas	0.00	0.00	0.00	0.00	0.00	0.00
30 Petrochemical	-0.10	-0.33	-0.07	-0.22	-0.05	-0.14
31 Other manufacturing	-0.76	0.11	-0.57	-0.09	-0.33	0.03
32 Vehicle	-1.35	-2.01	-0.93	-1.15	-0.56	-0.58
33 Metallurgical	-0.43	-1.04	-0.30	-0.68	-0.19	-0.42
34 Commerce	0.14	0.43	0.09	0.28	0.06	0.17
35 Transport	-0.04	-0.12	-0.03	-0.08	-0.02	-0.05
36 Services	0.05	0.23	0.04	0.17	0.02	0.11
37 HOU	2.20	7.31	1.55	4.92	1.02	3.16
Total	**44,345.87**	**108,723.50**	**29,985.17**	**69,488.66**	**19,047.93**	**42,539.27**

Model results.

Adopting an average coefficient between the industries with more advanced technology and industries with outdated technology and higher rates for water use. It became possible to explain, in some cases, why the industry reduces the water use. On the other hand, the expansion of irrigated area in the country increases water consumption for the main crops in each scenario in order to maintain the proportionality of the technical coefficient for crops, products, and human consumption.

It is necessary to take caution in order to analyze the amount of water in Mm^3 in the simulations. The magnitude of the country, population growth and overcrowding in large urban centers are conditioning factors in changes in consumption of water resources, especially for irrigated agriculture in arid and semi-arid regions such as the north-central Bahia; in the Interior (west) of the states of Sergipe, Alagoas, Pernambuco, Paraiba, Rio Grande do Norte; in the Center-South region of Ceará; as well as in the South and Southeast of Piauí. The warm climate and the irregularity of rainfall favor the planting of certain crops which, along with irrigation techniques, promote regional development.

Table 10 shows the simulation results for the expansion scenarios of irrigated agriculture. The biggest water use (Mm^3) correspond to CanaDeAcucar (sugarcane) followed by ArrozCasca (Rice), reflecting a clash in the irrigated regions portion that present a high production of these crops. In Brazil, sugarcane is one of the main crops for agribusiness and is integrated with national energy and raw materials for various industrial products. The culture has expanded its planted area over the years, with an average growth of 10% per year (PAM, 2015). Its main producing regions are the states of São Paulo, Alagoas, Pernambuco and Minas Gerais, but its irrigated areas would also be expanded to states such as Piauí, Bahia and Rio Grande do Norte.

Rice is produced in the states of Rio Grande do Sul, Santa Catarina, Tocantins and Ceará (the main producing municipality in Ceará is in Iguatu) and has the flooding system as its main production technique. The efficiency of water use is hindered in many cases due to the lack of flow control monitoring.

The state of Tocantins is the largest rice producer in the North, and its irrigation is practiced mainly in so-called lowlands or plains of the valleys of the Araguaia and Tocantins rivers. The state has a historical average annual rainfall of 1,638 mm (millimeter / year) (ANA, 2013). In the harvest of 2014 there were produced over 540 thousand tons in the state of Tocantins (Conab, 2015) and production reached 9,835,316 (tonnes) in the three states (Rio Grande do Sul, Santa Catarina and Tocantins), confirming the economic importance of the culture in these regions. The state of Rio Grande do Sul is the largest regional producer of rice in Brazil, producing more than 70% of all irrigated rice in the country.

The simulation shows that the amount of Mm^3 water use would is higher for Forestry, reflecting the potential expansion of irrigated area in the Amazon region, and not necessarily due to the excessive use of water. Because, the average technical coefficient considered for Palm was 1.46 l/s /ha (liters per second per hectare) and 1.58 l/s /ha for Rubber Trees and 0.69l /s /ha for Assai, typical regional crops and reflected in the simulation. The Amazon is a rainy region with historical average annual rainfall of 2,461 mm/year (ANA, 2013).

It is worth mentioning that irrigated activities generally have higher rainfed productivity activity arising from the improvement in technical changes required in the activity. In this sense, the increase in irrigated system productivity is also reflected in the industry. For example, with the expansion of the sugarcane irrigated area and increased productivity, the water use is intensified for the UsiRefAcucar activities (sugar plants) and alcohol (bioethanol plants) in the three simulations (CEN1, CEN2 and CEN3), which may cause a low in water use for the gas sector (decrease in input activity). The activities associated with the usage of oil, such as Petroquímic

(Petrochemical) have reduced water use in the simulations. The results also show the growth in water use in the service sector and in household consumption (HOU). The household consumption was adjusted by population growth and activity services according to the growth of PIB.

Water usage in industrial production is intrinsically linked to factors such as production capacity, methods, technological and operational practices, business culture and climatic conditions to which companies are subject in their operating region. The Brazilian industrial system has a series of standards and licensing practices governing the various sectors of the economy related to environmental licensing, effluent standards and toxicity, among others, such as the resolution 54/2005 (Potable water reuse) establishing the reutilization of water.

The Brazilian population is supplied by surface water and groundwater. The greater or lesser intensity of usage of these sources depends on the water location, as well as technical, financial and institutional capacity for better utilization of water resources (ANA, 2010). As described in Cardoso et al. 2008 major cities of the North and Northeast regions are supplied partially or completely by wells, but there are shortages on studies on regional aquifers, and investment is necessary. Therefore, the value in million cubic meters (Mm³) associated with the growth of irrigated area, production and population growth in Brazil should present amounts consistent with the simulations proposals. Table 11 summarizes the accumulative deviation for water consumption in (Mm³) and area (hectares) by region.

Table 11. Accumulative policy deviation in Mm³/year and hectares by region in 2025.

Region	**Mm³/year**			**Area (hectares)**			**Mm³/Hectare/year**		
	CEN1	CEN2	CEN3	CEN1	CEN2	CEN3	CEN1	CEN2	CEN3
1 Rondonia	566	605	384	46.625	49.854	31.658	0,012	0,012	0,012
2 Amazon	24,708	12,688	8,313	1.376.763	722.209	473.497	0,018	0,018	0,018
3 ParaToc	19,251	8,492	5,192	664.903	300.046	183.942	0,029	0,028	0,028
4 MarPiaui	4,072	1,421	857	86.104	31.399	18.982	0,047	0,045	0,045
5 PernAlag	503	255	149	5.584	2.836	1.659	**0,090**	**0,090**	**0,090**
6 Bahia	9,372	6,805	4,035	197.716	143.786	85.269	0,047	0,047	0,047
7 RestNE	1,473	1,094	641	21.441	14.916	8.752	**0,069**	**0,073**	**0,073**
8 MinasG	9,571	6,076	3,597	330.611	209.709	124.178	0,029	0,029	0,029
9 RioJEspS	739	54	31.77	13.445	1.051	614	0,055	0,052	0,052
10 SaoPaulo	4,554	4,062	2,391	154.122	137.663	81.055	0,030	0,030	0,030
11 Parana	613	385	230	65.386	40.957	24.450	0,009	0,009	0,009
12 SCatRioS	4,643	4,070	2,391	110.841	95.838	56.313	0,042	0,042	0,042
13 MtGrSul	7,823	7,588	4,639	224.944	216.849	132.573	0,035	0,035	0,035
14 MtGrosso	5,820	5,242	3,281	375.721	338.157	211.672	0,015	0,016	0,016
15 Central	12,991	10,652	6,399	457.994	373.612	224.633	0,028	0,029	0,028
Total	**108,723**	**69,489**	**42.539**	**4.132.200**	**2.678.882**	**1.659.247**	**0,56**	**0,56**	**0,55**

Model Results.

The simulation results show that the demand for water is greater in CEN 1, with a total of 108,723.5 mm³ / year of water for 2025. The region that would present greater use of water resources in CEN1, CEN2 and CEN3 are the regions of the Amazon and ParaToc. The results show that the demand for water is greater in CEN 1, with a total of 108,723 mm³/year of water for 2025. The greater use of water resources in CEN1, CEN2 and CEN3 are in the Amazon and ParaToc regions. However, in terms of water use per hectare (Mm³/hectare/year), the highest ratio occur in the PernAlag (0.09) and RestNE (0.069) regions, which are supplied by Atlantic Western Northeast, Parnaíba and São Francisco basin, which have lower water flow to supply states with considerable portion of arid and semi-arid areas.

The northeast region of Brazil (PernAlag, RestNE, Bahia and MarPiaui) has a land area which occupies around 18% of the country (Table 8), with the largest coastline and prevalence of tropical semi-arid climate. The PernAlag region had the highest ratio Mm³/hectare. The main crops such as sugarcane, watermelon, beans, banana, mango, tomato, rice, among other crops would lead to greater impact on water among regions in the simulations. The largest irrigated crop in Pernambuco and Alagoas in 2006 was the sugarcane, which has been expanded and designed in the simulation, as well as, other crops of the northeast region.

The comparison between demand and supply of regional water in m³/s (cubic meters per second) is difficult because the watersheds do not have the same geographical delimitations of the regions in question, and basins provide water for more than one region. Thus, the ideal would be the comparison with the regional micro basins. However, for an initial comparison between the result of the proposed model for regional supply and demand for water, the Table 12 shows water availability as the sum of the basins in the dry season with a flow rate of 95% (Q95%), and the result of the cumulative policy for 2025 m³/s in the Brazilian regions.

Table 12. Water quantity in m³/s (cubic meters per second) in the simulations and national hydrographic basins.

Regions	Basins	water availability / drought	Water use in m³/s		
		Q95 m³/s	CEN1	CEN2	CEN3
Rondonia	Amazônica	73.748	18	19	12
Amazon	Amazônica, Atlântico Nordeste Ocidental e Tocantins-Araguaia	79.515	783	402	264
ParaToc	Tocantins- Araguaia	5.447	610	269	165
MarPiaui	**Atlântico Nordeste Oriental, Parnaíba**	**470**	**129**	**45**	**27**
PernAlag	Atlântico Nordeste Oriental e São Francisco	1.987	16	8	5
Bahia	Atlântico Leste e São Francisco	2.201	297	216	128
RestNE	**Atlântico Nordeste Oriental, Parnaíba, Atlântico Leste**	**775**	**47**	**35**	**20**
MinasG	Atlântico Leste Atlântico Sudeste, Paraná e São Francisco	9.102	303	193	114
RioJEspS	Atlântico Leste e Atlântico Sudeste	1.414	23	2	1
SaoPaulo	Atlântico Sudeste, Atlântico Sul e Paraná	7.548	144	129	76
Parana	Atlântico Sudeste, Atlântico Sul e Paraná	7.548	19	12	7
SCatRioS	Atlântico Sul, Uruguai	1.212	147	129	76
MtGrSul	Paraguai e Paraná	6.574	248	241	147
MtGrosso	Amazon, Paraguay and Tocantins-Araguaia	79.977	185	166	104
Central	Parana, San Francisco, Tocantins-Araguaia	13.135	412	338	203
Total			3.383	2.203	1.349

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Regions as those of MarPiau (Maranhão and Piaui) are supplied by the Atlantic Wester Northeast and Parnaiba basins, which also supply RestNE and PernAlag (Atlantic Easter Northeast). Therefore, the third column shows water availability in drought in m³/s as the total sum of the basins in each region. Thus, the Atlantic South basin supplies the area of ScatRioS (Santa Catarina and Rio Grande do Sul) and also supplies SaoPaulo and Paraná, which are populated states (projection of 81,933,177 inhabitants for 2025) with high industrial and agricultural development, climate variability less susceptible to periods of prolonged drought and supplied by basins with good drought flows (table 1).

The Northeast region receives water from the San Francisco, Parnaiba, Atlantic Eastern Northeast, Atlantic Western Northeast and Atlantic Eastern basins (the latter also supplies the states of Minas Gerais and Espirito Santo). However, about 70% of the northeastern area is part of the so-called polygon of droughts, which are regions susceptible to periods of prolonged drought. The INPE (National Institute for Space Research) reports that, with global warming, the temperature in the tropics tend to increase from 2 to 6 degrees Celsius in the upcoming decades. The most affected regions would be the Amazon and the Northeast. The semi-arid region will tend to become more arid and have the intensity of droughts increased with reduced available water. Susceptibility to climate change which will impact on vegetation, biodiversity and activities that depend on water resources (MARENGO, 2007a; MARENGO, 2007b).

This region has the lowest water availability among the regions analyzed and the simulation results showed the highest ratio of water demand per hectare in this region. It has a high climate variability and different levels of human development. In Brazil, the northeast region is one of the main regions targeted by the Federal Government’s projects of public irrigation and water resources management. The main public agencies responsible for development and regional progress with the use and management of the water resources are Development Company of the São Francisco and Parnaíba River's Valley (Codevasf) and the National Department of Works to Fight Drought (DNOCS).

Comparing the results of the simulations (CEN1, CEN2 and CEN3) with the information released about the use of water for irrigation in 2014 of 1,252.73 m³/s (ANA, 2015). It would be of 37% of the simulated water demand for 2025 in CEN 1 (3,383 m³ / s), more than 50% of the simulated water demand in CEN2 (2,203 m³/s) and more than 90% of the simulated water demand for CEN3 (1,349 m³/s) considering all the activities of the model.

The Northeast (PernAlag, RestNE, Bahia and MarPiaui) is the region requires the biggest advance in the management of water resources and should be the focus of future simulations. The simulation results show the CEN 1 expansion of 310,845 hectares and the use of water resources of 15,420 Mm³; in CEN 2, an expansion of 192 937 hectares and a water use of 9,575 Mm³; and in CEN 3, expansion of 114 662 hectares and using 5.684 Mm³, the equivalent of 0.05 Mm³/ha/year for the three simulations.

The North region would expand the irrigated area in CEN 1, "water for all", to 2,088,291 hectares (Table 11) by 2025, using 44,526 Mm³ water (irrigated agriculture, industrial activities and household consumption water use). The simulation for CEN 2, "water for some", would expand to 1,072,109 hectares and require 21,875 Mm³ of water. The simulation for CEN3, "water for few" would expand to 689,097 hectares and a water use in the country of 13,890 Mm³, implying consumption equivalent to 0.021 Mm³ / hectare / year in the region in each scenario.

The Southeast (São Paulo, MinasG, RioJEspS) would advance in irrigated agriculture, especially in MinasG. The simulation results show in CEN 1 an expansion of 498,178 hectares and use of water resources of 14,864 Mm³ of water; in CEN 2, an expansion of 348,423 hectares and the use of 10,192 Mm³; and in CEN 3, an expansion of 205,847 hectares and 6,019 Mm³ of water, equivalent to 0.030 Mm³ / ha / year.

The South (Paraná, SCatRioS) is the smallest Brazilian region in terms of territory. However, it has the best social indicators, located almost entirely in the temperate region, with subtropical climate and temperatures below that of the other regions of the country. In CEN 1 expand 176,227 hectares with the use of 5,256 Mm³ in CEN 2 expansion of 136,795 hectares and the use of 4,455 Mm³ and CEN 3 expansion of 80,736 hectares and the use of 2,621 Mm³, equivalent to a use Mm³ 0.032 / hectare / year.

The Midwest (Mt Gr South, Central and MtGrosso) is a region that has been advancing in irrigated agriculture over the decades (Table 2 and 3), especially in MtGrosso and MTGrSul. The simulation results showed that in CEN 1, expansion of the irrigated area would be to 1,058,659 for Mm³ 26,634 of water use, in CEN 2 expansion would be to 928,618 hectares for an usage of Mm³ 23,482, and CEN 3, expanding 568,878 hectares and sing of 14,319 Mm³, with an impact of 0.025 Mm³ / ha / year.

It is worth noting that the comparison of water demand exclusively by its water availability in the region does not describe in its amplitude the regional potential for the expansion of irrigated agriculture. As pointed out in (PNRH, 2006; ANA, 2010; MI, 2014) all regions need investment in infrastructure and expansion of the regional supply system in order to attend future water demand.

8 FINAL REMARKS

The study simulated the sectoral and regional demand for water use in Brazil through the expansion of irrigated agriculture. The exercise dedicated to irrigated agriculture used information about crop productivity, technical coefficients in the product level, historical bases for the regions, and showed the model results in three different scenarios adapted from PNRH. In principle, the research contributes to the simulation of water demand in Mm³ / year in a CGE model.

The data does not reveal the quality of water resources in Brazil nor extraction costs, necessary investments or other items that may identify future water stress. For this to take place, improvements in water modules and the inclusion of new regional data provide tools for the advancement of knowledge on the demand of regional water resources in Brazil, especially in areas that require more attention, such as MarPiaui and RestNE

However, the simulation results illustrate the use of water for users in the regions in three different scenarios focusing on the expansion of irrigated agriculture. The region with the highest growth potential for irrigated agriculture and use of water resources would be the North in all the simulations (Amazon, Rondonia, ParaToc), supplied by the Amazon Atlantic Western Northeast and the Tocantins-Araguaia basins.

Indeed, the climate heterogeneity and the regional hydrogeology, including exploration and risks, require directed research. The simulation highlighted the MarPiaui and RestNE as the regions as the main areas for discussion of water scarcity. The regions of Minas Gerais, Mato Grosso, Mt GrSul and Central are able to progress in irrigated agriculture because of the regional water availability, especially the MtGrosso region that also receives water from rivers that compose the Amazon basin. As a result of the simulations it is also observed that the MinasG region was the third region of greatest expansion of irrigated area in the simulations (Table 7), followed by the Central region. The main irrigated crops would be sugarcane, soybeans, corn, and rice.

The Northeast region (PernAlag, RestNE, Bahia and MarPiaui) was the second region with the lowest expansion of irrigated area, just behind the South. However, the impact on water resources in this region was twice as big as the others, i.e, water demand needed to reflect the entire cycle of irrigated crops in the Northeast, plus population growth associated with productive progress would require greater water availability in the basins. It cannot be affirmed, up until the present date, whether the regional water availability is sufficient to satisfy the projected water demand.

The SaoPaulo region has good water availability as well, in relation the simulated expansions for irrigated agriculture. It has infrastructure (roads, hydroelectric, waterways), and irrigated agriculture is practiced especially in the northern and midwestern regions, where sugarcane and orange, corn, beans, soybeans, potatoes, crops are cultivated. The irrigated area represented in the base simulation (Table 7) was the second largest area among the regions and as result of policy deviation accumulative to 2025 (Table 11) the ratio Mm^3 / hectare / year would be below the national total.

Therefore, the simulations showed that irrigated agriculture is the largest impact activity in regional water demand in the country. The expansion of crops such as sugarcane and rice in areas that have traditionally faced prolonged periods of drought would demand for high water availability and major investments. The study illustrated the impact of population growth projected in the regions, as well as how the adoption of a steady growth of 2.5% of GDP would affect the demand of water use in various industrial activities, services and household consumption, indicated reductions in certain activities (oil, mining) and expansion activities in the agricultural production chain and livestock (UsiRefAcucar, Dairy).

However, the result of this simulation is regarded with caution; this is the first exercise with water computable data in Mm^3 / year prepared in product and region levels. There is still no clear nor certainty on the possible impacts of the advance of irrigated agriculture on regional water availability. Uncertainties are an obstacle for operational planning and management of natural resources in the country. However, the projections suggest that there are risks for water resources in Brazil, especially in the Northeast. In future studies, the inclusion of cost information, regional rainfall, climate change and other data that may serve to advance the sectoral and regional literature is suggested.

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ANEXO A

Tabela A1. Mudança na área irrigada por estado e cultura –CEN 1 – (Diferença Acumulada, Mha).

delirrlnd(D)	Rondonia	Amazon	ParaToc	MarPiaui	PernAlag	Bahia	RestNE	MinasG	**Total**
1 Rice	0,003	0,094	**0,382**	0,037	0,000	0,004	0,003	0,008	0,530
2 Corn	0,005	0,014	0,033	0,010	0,000	0,019	0,004	0,051	0,137
3 Wheat and others	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,005	0,005
4 Sugarcane	0,000	0,002	0,026	0,011	**0,004**	0,022	0,006	**0,111**	0,182
5 Soy	0,000	0,000	0,093	0,007	0,000	0,030	0,000	0,043	0,173
6 Farming	0,005	**0,118**	0,082	**0,017**	0,001	**0,071**	**0,008**	0,053	0,356
7 Manioc	0,006	0,111	0,017	0,005	0,000	0,004	0,000	0,001	0,144
8 Tabacco Leaf	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,001
9 Cotton	0,000	0,000	0,000	0,000	0,000	0,014	0,000	0,004	0,018
10 Citrus Fruits	0,001	0,019	0,028	0,000	0,000	0,002	0,000	0,007	0,056
11 Coffee	**0,022**	0,001	0,000	0,000	0,000	0,019	0,000	0,033	0,075
12 Forestry	0,004	**1,017**	0,003	0,000	0,000	0,013	0,000	0,015	1,052
Total	0,047	1,377	0,665	0,086	0,006	0,198	0,021	0,331	2,730

Model’s result.

delirrlnd(D)	RioJEspS	SaoPaulo	Parana	SCatRioS	MtGrSul	MtGrosso	Central	Total
1 Rice	0,000	0,001	0,006	**0,095**	0,046	0,019	0,017	0,185
2 Corn	0,000	0,012	0,013	0,001	0,023	0,098	0,047	0,193
3 Wheat and others	0,000	0,000	0,001	0,000	0,001	0,000	0,001	0,003
4 Sugarcane	**0,008**	**0,090**	0,020	0,000	**0,122**	0,045	**0,198**	0,484
5 Soy	0,000	0,004	**0,015**	0,010	0,031	**0,125**	0,082	0,266
6 Farming	0,001	0,013	0,005	0,005	0,002	0,017	0,081	0,123
7 Manioc	0,000	0,000	0,002	0,000	0,001	0,003	0,001	0,006
8 Tabacco Leaf	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
9 Cotton	0,000	0,003	0,000	0,000	0,000	0,065	0,008	0,076
10 Citrus Fruits	0,000	0,026	0,000	0,000	0,000	0,002	0,009	0,038
11 Coffee	0,003	0,003	0,002	0,000	0,000	0,000	0,007	0,016
12 Forestry	0,000	0,001	0,001	0,001	0,000	0,002	0,007	0,012
Total	0,013	0,154	0,065	0,111	0,225	0,376	0,458	1,402

Model’s result.

ANEXO B

Tabela B.1 Mudança na área irrigada por estado e cultura –CEN 2 – (Diferença Acumulada, Mha).

delirrlnd(D)	Rondonia	Amazon	ParaToc	MarPiaui	PernAlag	Bahia	RestNE	MinasG	Total
1 Rice	0,003	0,047	**0,164**	0,015	0,000	0,003	0,002	0,005	0,239
2 Corn	0,006	0,006	0,017	0,003	0,000	0,014	0,003	0,033	0,081
3 Wheat and others	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,003	0,003
4 Sugarcane	0,000	0,001	0,011	0,003	0,002	0,016	0,005	**0,070**	0,108
5 Soy	0,000	0,000	0,043	0,002	0,000	0,022	0,000	0,027	0,094
6 Farming	0,005	0,071	0,041	0,007	0,001	**0,052**	0,005	0,034	0,216
7 Manioc	0,006	0,064	0,009	0,001	0,000	0,003	0,000	0,001	0,084
8 Tabacco Leaf	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
9 Cotton	0,000	0,000	0,000	0,000	0,000	0,010	0,000	0,002	0,013
10 Citrus Fruits	0,001	0,011	0,014	0,000	0,000	0,001	0,000	0,004	0,031
11 Coffee	**0,023**	0,001	0,000	0,000	0,000	0,014	0,000	0,021	0,059
12 Forestry	0,005	**0,521**	0,001	0,000	0,000	0,009	0,000	0,010	0,546
Total	0,050	0,722	0,300	0,031	0,003	0,144	0,015	0,210	1,475

Model's result.

delirrlnd(D)	RioJEspS	SaoPaulo	Parana	SCatRioS	MtGrSul	MtGrosso	Central	Total
1 Rice	0,0000	0,0008	0,0040	**0,0834**	0,0452	0,0173	0,0142	0,1648
2 Corn	0,0000	0,0112	0,0082	0,0004	0,0218	0,0878	0,0380	0,1675
3 Wheat and others	0,0000	0,0002	0,0007	0,0001	0,0005	0,0002	0,0009	0,0026
4 Sugarcane	0,0005	**0,0804**	0,0123	0,0000	**0,1163**	0,0400	**0,1610**	0,4103
5 Soy	0,0000	0,0032	0,0093	0,0093	0,0301	**0,1132**	0,0678	0,2329
6 Farming	0,0001	0,0117	0,0030	0,0021	0,0015	0,0155	0,0655	0,0994
7 Manioc	0,0000	0,0003	0,0010	0,0000	0,0007	0,0024	0,0007	0,0051
8 Tabacco Leaf	0,0000	0,0000	0,0001	0,0002	0,0000	0,0000	0,0000	0,0003
9 Cotton	0,0000	0,0022	0,0003	0,0000	0,0004	0,0581	0,0068	0,0678
10 Citrus Fruits	0,0000	**0,0236**	0,0002	0,0000	0,0003	0,0015	0,0074	0,0329
11 Coffee	0,0004	0,0029	0,0015	0,0000	0,0002	0,0002	0,0054	0,0106
12 Forestry	0,0000	0,0012	0,0003	0,0004	0,0000	0,0020	0,0060	0,0099
Total	0,0011	0,1377	0,0410	0,0958	0,2168	0,3382	0,3736	1,2041

Model's result.

ANEXO C

Tabela C1.Mudança na área irrigada por estado e cultura –CEN 3 – (Diferença Acumulada, Mha).

delirrlnd(D)	Rondonia	Amazon	ParaToc	MarPiaui	PernAlag	Bahia	RestNE	MinasG	Total
1 Rice	0,002	0,029	0,100	0,009	0,000	0,002	0,001	0,003	0,146
2 Corn	0,004	0,004	0,010	0,002	0,000	0,008	0,002	0,019	0,049
3 Wheat and others	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,002	0,002
4 Sugarcane	0,000	0,001	0,007	0,002	0,001	0,009	0,003	**0,041**	0,065
5 Soy	0,000	0,000	**0,026**	0,001	0,000	0,013	0,000	0,016	0,057
6 Farming	0,003	0,047	0,025	0,004	0,000	**0,031**	0,003	0,020	0,134
7 Manioc	0,004	0,042	0,005	0,001	0,000	0,002	0,000	0,000	0,054
8 Tabacco Leaf	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
9 Cotton	0,000	0,000	0,000	0,000	0,000	0,006	0,000	0,001	0,007
10 Citrus Fruits	0,001	0,007	0,008	0,000	0,000	0,001	0,000	0,003	0,020
11 Coffee	0,015	0,000	0,000	0,000	0,000	0,008	0,000	0,012	0,036
12 Forestry	0,003	**0,342**	0,001	0,000	0,000	0,006	0,000	0,006	0,357
Total	0,032	0,473	0,184	0,019	0,002	0,085	0,009	0,124	0,928

Model's result.

delirrlnd(D)	RioJEspS	SaoPaulo	Parana	SCatRioS	MtGrSul	MtGrosso	Central	Total
1 Rice	0,000	0,000	0,002	**0,049**	0,028	0,011	0,009	0,099
2 Corn	0,000	0,007	0,005	0,000	0,013	0,055	0,023	0,103
3 Wheat and others	0,000	0,000	0,000	0,000	0,000	0,000	0,001	0,002
4 Sugarcane	0,000	**0,047**	0,007	0,000	**0,071**	0,025	**0,097**	0,248
5 Soy	0,000	0,002	0,006	0,005	0,018	**0,071**	0,041	0,143
6 Farming	0,000	0,007	0,002	0,001	0,001	0,010	0,040	0,060
7 Manioc	0,000	0,000	0,001	0,000	0,000	0,001	0,000	0,003
8 Tabacco Leaf	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
9 Cotton	0,000	0,001	0,000	0,000	0,000	0,036	0,004	0,042
10 Citrus Fruits	0,000	0,014	0,000	0,000	0,000	0,001	0,004	0,020
11 Coffee	0,000	0,002	0,001	0,000	0,000	0,000	0,003	0,006
12 Forestry	0,000	0,001	0,000	0,000	0,000	0,001	0,004	0,006
Total	0,001	0,081	0,024	0,056	0,133	0,212	0,225	0,731

Model's result.