THE EXPANSION OF IRRIGATED AGRICULTURE IN BRAZIL AND THE POTENTIAL REGIONAL LIMITATIONS[1]

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Resumo: A expansão regional da agricultura irrigada provoca um crescimento na produção de alimentos no país, minimiza os riscos para o agricultor e fortalece a segurança alimentar para as gerações futuras. No entanto, tem um efeito prejudicial na disponibilidade hídrica através de demandas de uso de água, o que pode intensificar situações de escassez microrregional. O modelo TERM-BR foi utilizado para simular cenários de expansão em áreas irrigadas com o objetivo de verificar o impacto no uso da água em 2025. Os cenários foram adaptados do Plano Nacional de Recursos Hídricos (PNRH) e simulações foram realizadas para áreas consideradas potencialmente adequadas para Irrigação com base no relatório do Ministério da Integração Nacional (MI). A agricultura de irrigação foi separada da agricultura de sequeiro em termos de produtividade diferencial. O Balanço Hídrico Climatológico (CWB) foi estimado para os estados do Nordeste a fim de comparar o abastecimento e a demanda de água regional. Os resultados para o Brasil sugerem impactos positivo sobre o PIB, investimento e consumo das famílias regionais. O resultado comparativo da CWB e do modelo TERM-BR para estados na região Nordeste aponta para possíveis problemas de disponibilidade de água nos estados de Alagoas e Pernambuco, especialmente.

Classificação JEL: Q15, Q25, Q38
Palavras Chave: Irrigação, demanda por água, Plano Nacional de Recursos Hídricos, Equilíbrio geral

Abstract: Regional expansion of irrigated agriculture causes a growth in food production in the country, minimizes risks for the farmer and strengthens food security for future generations. However, at the same time, it has a damaging effect on water availability, via demands for water use, which may intensify situations of microregional water scarcity[6]. The TERM-BR model was used to simulate expansion scenarios in irrigated areas, aiming at verifying the impact in the water use for 2025. Scenarios were adapted from the National Water Resources Plan (PNRH) and simulations were carried out for areas deemed potentially suitable for irrigation based on the Ministry of National Integration report (MI). Irrigated agriculture was separated from dry farming in terms of differential productivity. The Climatic Water Balance (CWB) was estimated for Northeastern States in order to compare regional water supply and demand. Results for Brazil suggest positive impact on the GDP, investment and use of regional families. The comparative result of the CWB and the TERM-BR model for states in the Northeastern region point to potential water availability problems in the states of Alagoas and Pernambuco in particular.

Keywords: Irrigation, water demand, National Water Resources Plan, General Equilibrium.
Classification JEL: Q15, Q25, Q38

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[6] The term region is designated to explain the regions of the TERM-BR model, the term state is used to designate the federal unity of the country, and the term microrregion is designated to characterize a given region within the state.

Introduction

The irrigated agriculture area has been growing constantly for the last 20 years in Brazil. The Brazilian Agricultural Census has registered a total of 1,959,810 irrigated hectares in 1985 and 4,545,532 hectares in 2006, a growth of 132% during the period. Estimations made by the National Water Agency (ANA) report a growth of 46% between 2006 and 2012, approximately 5.8 million hectares that year (ANA, 2013). Although the advancement of irrigated areas is important for the generation of income and increases in food production, the impact on regional water resources has been causing conflicts in some Brazilian regions. Reports from the Pastoral Commission for Land (CPT) show that, in 2013, 93 conflicts were about to water use - 37 of them in the Northeast region. In 2015, conflicts for the use of water peaked at a total of 135 nation-wide, 46 in the Northeast region (CPT, 2015).

Agriculture is, by far, the greatest user of water resources; it is the main activity for livelihood and both direct and indirect employment for the population, and contributes considerably for the national GDP. However, in Brazil, taxing related to water use is incipient and usage data is not featured in national accountability reports, which renders an analysis of water resources with economic models difficult.

The TERM-BR model was used to simulate scenarios of irrigated hectares expansion proposed by the National Water Resources Plan (PNRH) described in MMA (2006a) and based on areas potentially suitable for irrigation reported by the MI (2014). In order to highlight eventual state-level restrictions to water supply, a climatic water balance (CWB) was estimated for the states of Northeastern Brazil in order to compare it to the results simulated by the TERM-BR model. The impact of the expansion of irrigated areas on sectoral and regional water demands in Brazil were therefore simulated for 2015.

The Brazilian territory extends for 8.5 million km² and is organized into five geographic regions (North, South, Northeast, Midwest and Southeast), with 26 Federal Units (UF) plus Federal District (capital). About 89 % of the Northeast region's territorial extension is situated in a semi-arid region; it constantly faces difficulties related to droughts and low regional development, having many rivers classified as being in critical condition due to low water availability (ANA, 2014), which makes it a target for a series of regional studies for the formulation of public policies.

Literature related to droughts and climate vulnerability in the Northeast is vast, especially in the semiarid region, a focal point of so many socioeconomic and bio-physical studies (Nelson and Finan, 2009). However, adopted policies suggest the existence of limitations regarding long-term analysis, whereas drought-related vulnerability remains. Economic studies on the demand for water use in Brazil and computable models of general balance (CGE) in an interdisciplinary analysis are still incipient in the country.

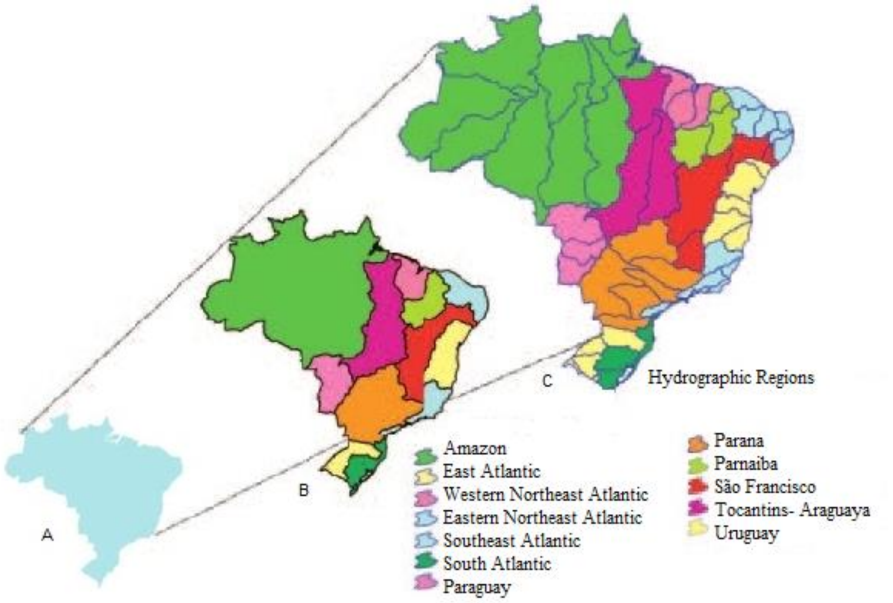
Therefore, this study intended to make a contribution in the following aspects. Firstly, the elaboration and aggregation of data for the matrix of original water by activity and by region. Secondly, as far as we know, this is the first time PNRH scenarios by MMA (2006a) are simulated in an integrated socioeconomic frame. Thirdly, a comparison between results for water demand with a regional database of water supply, estimated with detailed physical regional information is as yet unheard-of. We hope this paper will contribute to the clarification of aspects that are important to the management of water resources in Brazil, as well as to setting a path for the future expansion of this methodology for the whole country.

The National Water Resources Plan (PNRH) and Irrigated Agriculture

The PNRH constitutes a strategic set of inter-institutional actions and relations geared towards the improvement of water supply, both in terms of quality and of quantity, thus managing demands. The PNRH's strategic goals refer to (i) the improvement of water availability; (ii) the reduction of conflicts motivated by water usage and critical hydrological events and (iii) the valuing of water as a relevant socio-environmental good (MMA, 2006a). Four document notebooks were elaborated and divulged in 2006 and are integral to the plan. The first volume describes the panorama and the state of water resources in Brazil (MMA, 2006b), the second volume presents the plan's scenarios for 2020 (MMA, 2006a), the third volume reports the plan's directives (MMA, 2006c) and the fourth volume, national programs and goals (MMA, 2006d).

Water resources management is based on territorial sectioning of water basins, and management has gained momentum in the early 1990s when the Dublin Principles were agreed upon in the meeting in preparation for Rio-92 (WMO, 1992). Thus, PNRH, apart from considering the 12 disaggregated hydrographic regions into 56 planning units, it also takes into account regionalization in Special Planning Situations, which constitute territorial spaces, be they natural or derived from usage and occupation processes that might lead to another sectioning, whose limits need not necessarily coincide with those of a water basin (MMA, 2006b). Therefore, the plan takes into consideration the physical, biotic, cultural and socio-economical diversity of Brazilian hydrographic regions with regional and national integrations whose dissolution is in Figure 1.

Figure 1. PNRH Aggregation levels, (A) Brazil, (B) National Hydrographic Division (Sub-1_),(c) 56 planning units.



Source: MMA (2006b).

Having been implemented after the elaboration and promulgation of the Irrigation[7] and Agricultural Policies[8], the National Policy for Water Resources [9] is not specifically addressed in none of those policies (MMA, 2006b). Even though they already pointed out the need for conservation and e recuperation of natural, draining and irrigation resources, which allowed for the integration between the aforementioned policies and the elaboration of the PNRH. The use in irrigation tends to yield the greatest conflicts among intersectorial competitive uses because it is the greater use, which evidences the challenges faced by the National System for Management of Water resources (SINGREH), an organ which coordinates the integrated management of water by means of a complex of public and private institutions (MMA, 2006b).

Planning, by means of participatory construction of scenarios, implicated companies, governments and civil society organizations. Methodology for the construction of PNRH scenarios abided by several procedures ranging from the retrospective study of the system, morphological investigation, plausibility tests of the generated scenarios (MMA, 2006a), which, by their turn, are influenced by future developments both national and international. Data harvesting for PNRH shed light on the need to intensify researches on water usage in all regions of the country. The northeastern semiarid region is prominent in this sense, since it is a region endowed with great biological diversity, where many species of plants, legumes and fruits are found in areas susceptible to desertification (Marengo and Bernasconi, 2015). However, in areas susceptible to desertification, which comprehend the Brazilian semiarid and its surroundings, more than 80% of houses do not have a general water supply network, and circa 40 % are served by waters form streams and wells located outside their estates (MMA, 2004).

[7] Law no 8,171, dated January 17th, 1991.
[8] Law no 6,662 dated June 25th, 1979. National policies for irrigation were revised and sanctioned according to Law nº 12,787 dated January 11th.
[9] Law no 9,433 dated January 8th, 1997.

The growth of world population leads to pressures on the demand for foodstuff, which influences the practice of irrigation as one item of productivity control and increase. Despite the fact that irrigated areas have increased in the country during the last two decades, they are still relatively small, as can be seen in Table 1.

Table 1. Data relating to irrigated and planted areas in temporary and permanent cultures.

	Temporary Culture			Permanent Culture		
	Area (ha)	Irrigated area	%	Area (ha)	Irrigated area	%
North	1,837,143	103,945	6%	441,563	24,870	6%
Northeast	12,092,757	1,302,767	11%	1,595,151	197,517	12%
South	16,343,394	1,576,337	10%	406,255	25,317	6%
Midwest	12,264,580	777,796	6%	83,050	16,679	20%
Southeast	7,737,673	1,381,213	18%	2,520,623	509,691	20%
Brazil Total	**50,275,547**	**5,142,058**	**10%**	**5,046,642**	**774,074**	**15%**

Source: Elaborated by the author from data taken from the Agricultural Census of 2006 at IBGE (2009).

The Midwest region registered the highest expansion, with a 1262% growth between 1985 and 2012, influenced by commercial and agricultural policies begun in the 1970s, as pointed out by Helfand and Resende (2000). Other significant features of said increase are the implementation of a production system impelled by specific lines of financing, transportation, irrigation, territorial extension, land cost, which have been intensified with agricultural and irrigation policies. The region stands out also for having increased its national agricultural GPD participation, from 7.4 % in 1970 to 19.5% in 2009, as pointed out by De Castro (2014).

The advance in irrigated hectares is linked to risk control, and was aided by the advancement in system automation. In the states of Bahia and Pernambuco, for instance, irrigated fruit farming has allowed for the development of regional hubs of production and export (Correia et al 2001; Leite et al, 2016). We also point out that, from the years 2002-2012, Northeastern participation in the GDP averaged about 13.2%, and agriculture contributed circa 17.7 % (peaking in 2008 at 19.6 %) (IBGE, 2014). Therefore, Table 2 presents data related to irrigated hectares by states pertaining to the Northeast region in accordance with the country's main sources of statistical information.

Table 2. Increase in irrigated hectares in the states of Brazil's Northeast Region.

UF	**1985 (a)**	**1995/96 (b)**	MMA (2011)[10] **2006 (c)**	**ANA (2012) (d)**
Alagoas (AL)	27,814	156,996	416,101	222,684
Bahia (BA)	107,054	209,705	240,249	467,607
Ceará (CE)	67,304	108,998	99,657	133,336
Maranhão (MA)	24,034	16,521	42,083	43,681
Paraíba (PB)	18,895	63,548	81,027	65,522
Pernambuco (PE)	83,456	118,400	25,629	183,912
Piauí (PI)	13,560	18,254	22,200	34,225
Rio Grande do Norte (RN)	17,588	45,778	55,442	62,165
Sergipe (SE)	7,121	13,691	17,320	25,602
Total Northeast	366,826	751,891	1,212,120	1,238,734
Brazil Total	**1,959,810**	**3,121,648**	**4,478,586**	**5,797,073**

Elaborated by the authors based on data from: a) IBGE (1991); b) IBGE (1998); c) MMA (2011); (d) ANA (2013).

According to Buainain and Garcia (2015), public hubs of irrigation are under the responsibility of the DNOCS (National Department for Works Against Droughts) and the Codesvaf (The São Francisco and Parnaíba Valleys Development Company); they occupied 190.8 thousand hectares (63% Codevasf and 37%

[10] The MMA's estimate (2011) presents regional divergences in relation to data from the Agricultural Census of 2006; for more information, please consult the authors.

Dnocs), of this total circa 161.3 thousand hectares were used by agriculture in 2013. However, the Agricultural Census of 2006 in IBGE (2009) reported that Northeast region presented more than 1 million irrigated hectares in 2006 and, with the reduction of water availability (ex: pluriannual drought extending from 2012 to 2015), the conflicts numbers motivated by water usage in the region has been growing as years go by (Martins and Magalhães, 2015),

Conflicts motivated by water use due to reasons ranging from the threat of expropriation, non-fulfillment of legal procedures, destruction and/or pollution to access hindrance occasioned by clandestine barriers and water course deviation, among others. Table 3 shows numbers the evolution of conflicts motivated by water use in the states of the Northeast region and, the families numbers involved, which reached 14,518 in 2010.

Table 3. Conflicts motivated by water usage in the states of Brazil's Northeast region from 2006 to 2015.

	Evolution of conflicts by Federal Unit in the Northeast									
FU	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Alagoas		2				3		2	2	1
Bahia	3	2	7	2	15	9	8	21	26	27
Ceará	2	4	6	5	8	2	4	4	1	2
Maranhão		2	1	3	8	4	8		4	5
Pernambuco	3	7	2	2	5	11	5	5	8	9
Piauí		3	1	3		1	1			2
Paraíba	1		2	1		2	2	3		
Rio Grande do Norte	2	4	2		2	1			1	
Sergipe	2							1		
Northeast conflicts	13	24	21	16	38	33	28	36	42	46
Brazil total	45	87	46	45	87	68	79	93	127	135
% of Brazil's Northeast	**29%**	**27%**	**46%**	**35%**	**44%**	**48%**	**35%**	**38%**	**33%**	**34%**
Total of families implicated	**1,190**	**9,806**	**8,183**	**4,393**	**14,518**	**8,619**	**3,880**	**4,182**	**10,412**	**9,345**

Source: Authorial elaboration based on reports from the CPT (2016).

Please note that the percentage of conflicts in the Northeast is high in relation to the national total. In this sense, the dynamics of Brazilian economy has a direct influence on the increase of conflicts. The fulfillment of both internal and external demands is an important factor for economic performance and must be associated with a strengthening of the management system for water resources in an economic expansion scenario faced with the possibility of increase in conflicts due to an increase in water usage demand (MMA, 2006c).

Methodology

Term-BR and the water module

This research uses the TERM-BR model, an interregional computable model of general balance (CGE) of the bottom-up kinds, adapted to Brazil from the TERM model's theoretical structures developed for Australian economy (HORRIDGE, 2012).

The TERM-BR database utilizes mainly tables from the Brazilian Input-Product matrix for the year 2005 and allows for the use of other sources of regional data in order to complement studies. The model includes an annual recursive dynamic and a regional representation which, in the present version, has distinguished 15 Brazilian regions, 36 sectors plus final demand, 10 kinds of family relations and 20 kinds of work, classified by salary range. The complete structure of the TERM model database is detailed in Horridge (2012) and versions adapted for Brazil may be consulted in the studies of Dos Santos (2006); Fachinello (2008); Fachinello e Ferreira Filho (2010); Ferreira Filho and Horridge (2014).

The evaluation of water usage required adaptations to the TERM-BR model, with new equations which separated agricultural lands into irrigated agriculture and dry farming land. Thus, the increase of regional agricultural production depends on the growth of areas (irrigated and non-irrigated) and the productivity of cultures in each area. This relation is described by the following equations:

$$\mathrm{K = SHRi.Ki + SHRn.Kn} \qquad (1)$$

In which:

K=; Total Productivity; Ki = irrigated area productivity; Kn = non-irrigated productivity.

Equation (1) demonstrates the relation between irrigated (SHRi) and non-irrigated (SHRn) sections of land and their respective areas. By expanding the irrigated area (Ki), the total area (K) also expands; the use of water resources in regional irrigated agriculture grows in proportion to the expansion of irrigated area. Food supply grows more in the irrigated area in relation to the non-irrigated area due to the fact that productivity for irrigated culture is higher than productivity for dry farming (non-irrigated).

The variation of agricultural productivity, in aggregated terms (dK), depends on both the irrigated and non-irrigated sections (SHRi and SHRn), as well as variations pertaining to these sections (shrig and shrnig). If productivity in irrigated areas Ki > Kn, it follows that:

$$\mathrm{Kn = x.Ki}\ ,\ 0 < \mathrm{x} < 1 \qquad (2)$$

In which *x* represents the weighting variable of the non-irrigated area in relation to the irrigated area. Therefore, making all necessary substitutions and differentiations, we have in (5) the elasticity of productivity in relation to irrigated land.

$$\frac{\partial \mathrm{K}^*}{\partial \mathrm{shrig}} = \frac{\mathrm{SHRi}\,(1-\mathrm{x})}{(1-\mathrm{x})\mathrm{SHRi}+\mathrm{x}} \qquad (3)$$

In the present case, the variation (shrig) is an exogenous element in the model and determined by the economical policies and, that determine changes in productivity.

Water usage database

The database for the Brazilian water module required some steps which involved the technical coefficients of the MMA (2011) and Lisbon (2010), data from the Annual Industrial Research (PIA) at a product level, the Agricultural Census of 2006, the National Research for Household Sampling (PNAD), the National Research for Basic Sanitation (PNSB) were used. In tradition, in some cases interviews were conducted in companies belonging to specific sectors, elaboration of the productivity matrix and planted and irrigated areas per culture and region.

The detailed description of the database elaboration per activity (industry, agriculture, family demands and services) may be consulted in Ferrarini et al. (2016). Data for water usage (consumption) in millions of cubic meters (Mm³) were adjusted and the result for Brazil and for the Northeast by aggregated groups of activity can be seen in table 4.

Table 4. Water usage by activity and region in Millions of Cubic Meters for the year 2006

	Agriculture	Livestock Farming	Industry	Services	Families	**Total**
Brazil	20,084	3,216	18,745	516	2,971	**45,531**
Maranhão (MA)	180	100	61	14	101	**457**
Piauí (PI)	100	73	22	6	46	**248**
Ceará (CE)	490	74	493	16	101	**1,175**
RGNorte (RN)	496	25	119	7	44	**692**
Paraíba (PB)	631	36	184	8	49	**908**
Pernambuco (PE)	2,191	64	227	22	124	**2,628**
Alagoas (AL)	3,719	18	126	6	38	**3,906**
Sergipe (SE)	108	17	69	6	36	**236**
Bahia (BH)	1,126	238	721	25	149	**2,259**

Authorial elaboration.

The amount of water in use for irrigated agriculture is directly linked to the type of culture that is planted, as well as the region. The study relied on information on water usage technical coefficients for 57 cultures which were aggregated (12) and are described in the table of results.

Climate Water Balance and the Brazilian Northeast

Climate data from the CRU (Climate Research Unit, version 3,2) were employed in order to estimate the water balance in the Northeast region. The Thornthwaite and Mather method (1955) was used to derive the Climatic Water Balance (CWB) at monthly tipe steps and may be consulted, for instance, in studies (Doorenbos e Kassam, 1994; Amorim Neto, 1989; Pereira, 2005; Varejão-Silva, 2006). The CWB was estimated for the entire country and annual water surplus or deficit calculated. Therefore, figure 2 illustrates the states of the Brazilian Northeast and the crossing between water basins and states estimated for the water surplus in the CWB calculation.

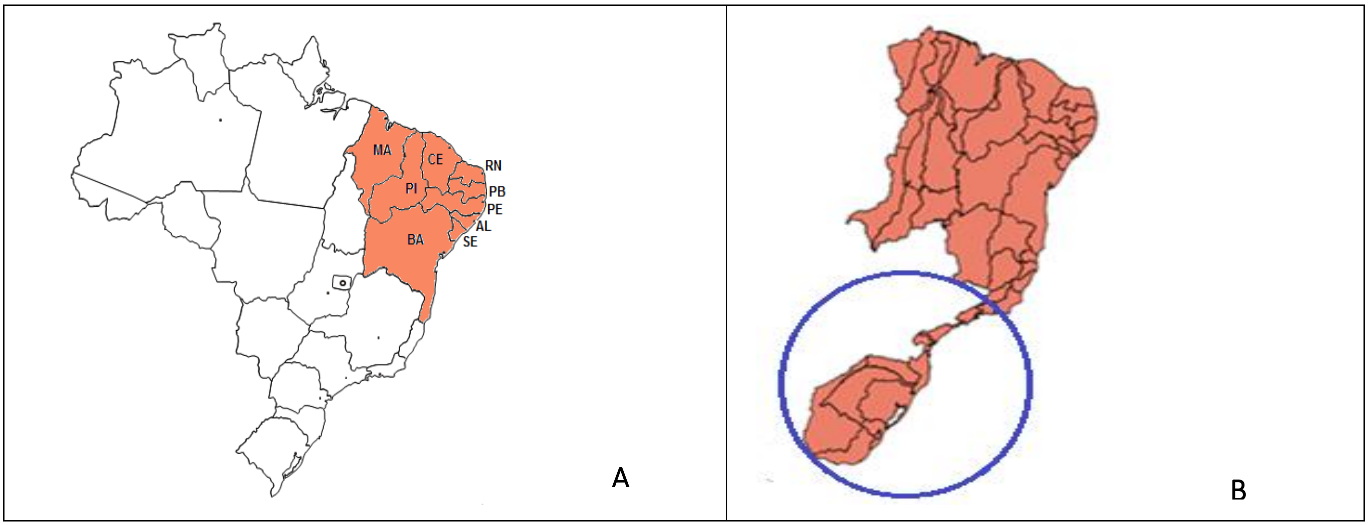


Figure 2. A: States of the Brazilian Northeast highlighted in the Brazilian map; B: Crossing between basin and states.
Source: Illustration of data estimated for the CWB.

The water demand database was structured at state or municipal level. The annual average water surplus estimated from CWB, was aggregated into larger units (hydro-regions) which takes into account watershed divisions and state boundaries (figure 2b) and the blue circle represents the interaction between basins and states of the South and Southeast regions of Brazil. The water supply at these hydro-regions was obtained from water surplus from CWB model minus integrated water demand for the hydro-region in question (from the TERM-BR model). When the balance proved to be positive (surplus minus consumption), water difference was transferred to hydro-region located immediately downstream.

PNRH Scenarios and closing of the CGE model.

The first step for the simulation was to update until 2012 with data observed for irrigated areas in Brazil[11]. In this historical simulation, it was also taken into consideration that the price of commodities increases annually 1% faster than the price of manufactured goods, the growth of Brazilian economy in terms of the GDP (Gross Domestic Product) followed information contained in the National Water Resources Plan (PNRH). For the SCEN 1 Increase of GDP of 4.5 %, in SCEN 2 GDP of 3.5% and, in SCEN 3 GDP of 1.5%.

Areas potentially suitable for irrigation classified as being of maximum interest for public intervention (MIIP) which was described in MI (2014) have been employed for the distribution of irrigated

[11] The year 2012 is the last year for which information referring to irrigated land is available in Brazil.

hectares regionally simulated. The simulated period ranged from the years 2013 to 2025. Therefore, PNRH scenarios were adapted for the current economic context:

Water for all (SCEN 1): Agriculture expands itself particularly throughout the Midwest (Mato Grosso do Sul, Mato Grosso, Goiás) and the Northeast (Bahia, Pernambuco, Rio Grande do Norte e Maranhão) and North (Rondônia, Tocantins and Pará). Annual growth of 170 thousand irrigated hectares with greater increment in the hydrographic region of Western Atlantic Northeast followed by the hydrographic region of Tocantins-Araguaya.

Water for some (SCEN 2): Agriculture expands throughout the Midwest (Mato Grosso, Mato Grosso do Sul, Goiás) and North (Rondônia, Tocantins and Pará). Areas that allow an annual growth of 120 thousand irrigated land. The greatest expansion of irrigated land would take place in the Hydrographic Region of the Parnaíba, followed by the Amazon region.

Water for few (SCEN 3): Emphasis on the production of sugarcane for fuel and cotton for the textile industry. Irrigated agriculture implicating an annual growth of 70 thousand hectares. The greatest increment of irrigated land would take place in the Hydrographic Region of the Parnaíba, followed by the Western Northeast Atlantic.

Changes in irrigated agriculture is related with the kind of culture, climate and water availability of each region. So, the results follow the presupposition that the technical coefficient by culture and hectare remained the same throughout the simulation of scenarios. In the policy closing, the section of irrigated land (*shrig*), by culture and region, is exogenous.

Results

Demand of water in Brazil

Results of the three simulations, which stand for scenarios described by PNRH, are summarized in table 5. The model was implemented for the 15 regions of the CGE model, with later emphasis on states belonging to the Northeastern region. Table 5 shows results of simulations for a few selected macro-economical variables. Change in water usage due to shock of policies is greatest in Scenario 1 (SCEN 1), and the macro-economical variable would raise the most in this scenario.

Table 5 Results of the policy in percent variables, aggregated variables and accumulated to 2025.

Description	Accumulate change Basis	Water for all SCEN1	Water for some SCEN2	Water for few SCEN3
Macro-economics (%)				
Family Consumption	118.23	0.080	0.056	0.0318
Real investments	151.86	0.189	0.145	0.0923
Costs for Government	89.79	0.080	0.056	0.0319
Export Volume	75.83	0.145	0.109	0.0633
Real salaries	60.32	0.170	0.120	0.0654
Real GDP	103,17	0.105	0.074	0.0416
Water usage				
National water usage (Mm³/year)	27,356	7,554	5,349	3,007
National water usage (% change)	66.50	10.56	7.92	4.97
Irrigated area				
Change in irrigated area (Mha/year)		2.49	1.77	1.00

Result of simulation.

Note: The first column (basis) shows the accumulative percent change over the simulation in the 2005-2025 period. The other columns show deviation in policy in relation to the basis. For instance, in scenario 1 family consumption in 2025 is 0.080 larger in relation to the basis.

National results for changes in irrigated areas in thousands of hectares (Mha) are consistent with goals set out in the PNRH[12] and show that the expansion of the area in SCEN1 would reach 2.49 (Mha), the greatest impact on water resources of all three scenarios. Family consumption, investments and salaries grow due to income generated by the boost in productivity by culture. Expansions of irrigated land contribute to the increase in agriculture productivity and average national income.

Water usage in SCEN1 - "Water for all" - is more intense, and would engender an increase in relation to the basis of +10.56 % accumulated in 2025 (a 7,554 Mm³ increase in water). Policy results for all scenarios show that the water use in SCEN 1 would have the most potential of leading to environmental problems and restricting access to water in certain regions of the country.

The policies results would generate positive impacts on GDP growth, investment, and regional household consumption. The largest contribution to the variation in real regional GDP would occur for Mato Grosso state (MtGrosso), of +1.17%, + 0.82%, and + 0.47% for the SCEN 1, SCEN 2, and SCEN 3, respectively. The positive impact, on regional GDPs, is associated with the productivity of irrigated agriculture, which would also promote the expansion of the production chain for the sectors of the food industry. The simulations suggest that the expansion these areas would generate positive impacts for the variation in GDP and investment for all regions and in all scenarios.

The irrigation could expand in North region in the states of Rondônia, Pará and Tocantins (ParaToc) as shown in table 6. In this case, impact on water usage would be greatest in the ParaToc region (+ 34.07% in SCEN1).

Table 6. Percentage variation in the usage of water by region as result of accumulated policy deviation.

	SCEN 1		SCEN 2		SCEN 3	
Regions	Areas (ha)	Water (in %)	Areas (ha)	Water (in %)	Areas (ha)	Water (in %)
North	**398,006**		**291,575**		**169,948**	
Rondônia	21,867	11.78 %	13,148	7.54 %	7,433	4.91 %
Amazon	147,579	36.34 %	110,872	29.70 %	66,717	21.24 %
ParaToc	228,560	34.07 %	167,555	26.05 %	95,798	16.33 %
Northeast	**153,597**		**112,248**		**64,419**	
MarPiaui	84,142	30.91 %	61,953	23.82 %	35,729	15.16 %
PernAlag	628	0.09 %	427	0.06 %	290	0.04 %
Bahia	66,553	7.95 %	48,304	6.00 %	27,425	3.68 %
RestNE	2,274	0.49 %	1,564	0.36 %	975	0.23 %
Midwest	**1,022,307**		**712,632**		**402,946**	
MtGrSul	155,014	29.59 %	109,669	21.84 %	59,143	12.89 %
MtGrosso	612,380	92.56 %	420,039	65.54 %	242,789	41.44 %
Central	254,913	26.74 %	182,924	19.93 %	101,014	11.85 %
Southeast	**408,783**		**287,025**		**161,371**	
RioJEspS	17,156	1.76 %	12,666	1.39 %	7,355	0.93 %
MinasG	320,785	16.38 %	222,763	12.06 %	124,852	7.58 %
SaoPaulo	70,842	1.32 %	51,596	1.04 %	29,164	0.68 %
South	**485,444**		**354,335**		**201,715**	
Parana	197,030	6.61 %	144,352	5.28 %	82,540	3.58 %
SCatRioS	288,414	8.88 %	209,983	6.84 %	119,175	4.29 %
National Total	**2,468,137**		**1,757,815**		**1,000,399**	

Result of the simulation

Note: Some states are agreggated into larger regions: Amazon (Amazon, Acre Roraima, Amapá), ParaToc (Pará and Tocantins), MarPiaui (Maranhão and Piauí), PernAlag (Pernambuco and Alagoas), RestNE (Ceará, Sergipe, Rio Grande do Norte and Paraíba), MinasG (Minas Gerais), RioJEspS (Rio de Janeiro and Espírito Santo), ScatRioS (Santa Catarina and Rio Grande do Sul), MtGrSul (Mato Grosso do Sul), MtGrosso (Mato Grosso), Central (Goiás and Distrito Federal).

[12] Policy scenarios for the expansion of irrigated land have taken into consideration the current legislation of the Forest Code (law nº12,651/2012) described in MI (2014).

The advancements of irrigated agriculture could generate income to local farmers, broaden the irrigation structure and minimize production loss. Mato Grosso state present the greatest potential for expansion of irrigated areas, being the third largest state in the country, with a high volume of fresh water, numerous rivers, aquifers, springs, and the planet's largest floodable area (called Pantanal). For this state, the simulation results in SCEN 1 show that an expansion of 612,380 hectares, would raise the water use in +92,56% in the first scenario. The main crops in the region are supposed to be corn, soybean, cotton, sugar cane, and other farming products. However, the largest expansion in the sugar cane production occurs in the states of Mato Grosso do Sul and Goiás.

The southern region of the country receive surface water by Paraná, Uruguay and Southeast basins. With a subtropical climate, the region exerts high economic influence over the country. The state of Rio Grande do Sul, for example, is the largest producer of irrigated rice: almost 90% of all its areas planted with rice are irrigated and has irrigable areas expansion potential of over 1,500,000 hectares according to the MIIP (maximum interest of public intervention). In this sense, the results of three simulations represent a small portion of the region's potential for expansion. The culture of rice, soybeans, and other crop products would be the ones with the highest potential, especially for rice.

The São Paulo state also presents good water availability regarding the expansions in the simulation. It has an infrastructure (highways, hydroelectric plants, waterways) that favors the expansion. Besides, irrigated agriculture is practiced, especially towards the northern and mid-western parts of the state where sugar cane, orange, corn, beans, soybeans, and potatoes are the predominant crops.

The results per crop in the irrigated agriculture is on table 7. Changes in the consumption of water resources, especially for the irrigated agriculture in arid and semiarid regions, such as the mid-northern part of the state of Bahia; the inland Sergipe, Alagoas, Pernambuco, Paraíba, Rio Grande do Norte, Ceará South Central region; The south and southeastern parts of Piauí are strongly affected by the hot weather and uneven rainfall distribution.

Table 7. Police deviation results, irrigated hectares and the result in million m ³ of water for users of irrigated agriculture in Brazil.

Crops	SCEN 1			SCEN 2			SCEN 3		
	Hectares	(m^3)[1]	%	Hectares	(m^3)	%	Hectares	(m^3)	%
Rice	520,948	1,808	29%	379,394	1,318	21%	215,076	748	12%
Maize grains	310,941	480	64%	226,119	349	47%	129,651	201	27%
Wheat and Cereals	11,465	13	45%	8,157	9	31%	4,461	5	18%
Sugar Cane	549,342	2,940	19%	380,084	2,030	13%	205,888	1,097	7%
Soybeans	442,251	654	96%	303,086	437	63%	176,411	254	36%
Other crops	242,212	587	22%	176,900	427	16%	104,030	251	9%
Cassava	48,626	95	58%	35,505	69	42%	20,617	40	24%
Tobacco	1,615	0	5%	1,181	0	4%	672	0	2%
Cotton	109,250	195	91%	79,461	142	67%	45,683	82	39%
Citrus Fruits	44,972	143	25%	32,391	103	18%	18,480	59	10%
Coffee	61,891	170	18%	43,478	120	12%	24,926	69	7%
Veg. Exploration	124,631	442	121%	92,057	327	90%	54,503	194	53%
Total	**2,468,144**	**7,528**		**1,757,813**	**5,331**		**1,000,398**	**2,998**	

Results of the simulation
Note [1]: million m^3.

The sugar cane crop stand out in all scenarios, being an important culture to the country (both for the domestic and external markets), provides a series of derivatives, such as sugar, ethanol, and its bagasse is used in the cogeneration of energy. In the preliminary analysis of the data, this culture presented a total of 6,390,474 planted hectares according to the Municipal Agricultural Production (PAM) in PAM (2006). Sugar cane planted area saw a growth of 59% between 2006 and 2015 (10,161,622 hectares in 2015).[13]

Therefore, the results of the policy in SCEN 1 would expand the irrigated area of sugarcane in + 549,342 irrigated hectares, this culture would be the most intensive on water resources, followed by the culture of the rice, produced mainly in the states of Rio Grande do Sul, Santa Catarina, and Tocantins. The state of Tocantins is the largest rice producer in the North region and irrigation is practiced mainly in the so-called lowlands or plains of the valleys of the Araguaya and Tocantins rivers.

The aggregate "other crops", produced in all Brazilian states, represents the largest use of water in the state of Bahia, Tocantins, Mato Grosso, Mato Grosso do Sul, Minas Gerais, and Goiás. This foodstuff group includes agricultural crops such as tomatoes, avocados, peanuts, potatoes, peas, onions, beans, sunflower, pepper, among others. It encompasses many cultures that are essential for regional development and income generation, and it also ensures the supply of foodstuff like beans, peas, and potatoes, which, added to the rice crops, are staple foods on the regular menu of the Brazilian population.

The comparison of water demand as exclusive criteria the water availability does not describe in full scale the potential for the expansion of agriculture. In all regions, require infrastructure investments and expansion of the regional supply system in order to meet these expansions of water demand. The Northeast region, except for the states of Maranhão, Piauí and Bahia, did not obtain major expansions of irrigated area due to low water potential in the region. Thus, the following session details results for the states of Brazil's Northeast and compares these with the estimated water availability from the CWB.

Effects of the increase in irrigated area in northeastern Brazil over water resources

As stated earlier in this section, here we will discuss in greater detail the results for the northeastern region of Brazil, the most critical in terms of availability of water resources. The results of SCEN 1[14] for water use was disaggregated (user and state) and the simulation were used in regional water balance estimates. Therefore, tables 8 and 9 present the results for the expansion of irrigated areas by culture in the northeastern states and the use of water in million m³.

Table 8. Irrigated areas (in hectares) as a result of the SCEN 1 policy accumulated to 2025.

Crops	MA	PI	CE	RN	PB	SE	PE	AL	BA	Total
Rice	11,473	24,755	75	25	26	83	89	58	1,455	38,039
Maize grains	4,604	4,805	152	33	83	57	10	1	6,757	16,502
Wheat and Cereals	0	0	0	0	0	0	0	0	30	30
Sugar Cane	9,249	1,391	47	490	504	299	72	96	6,744	18,892
Soybeans	7,254	0	3	0	0	0	0	0	10,177	17,434
Other crops	3,911	11,493	157	77	54	64	200	10	24,149	40,115
Cassava	4,320	636	1	2	1	10	31	31	1,425	6,456
Tobacco	0	0	0	0	1	1	0	4	84	90
Cotton	0	0	0	4	5	0	0	0	4,700	4,709
Citrus Fruits	75	176	2	0	0	20	14	9	545	841
Coffee	0	0	0	0	0	0	1	0	6,434	6,435
Veg. Exploration	0	0	0	0	0	0	2	0	4,051	4,053
Hectares	**40,887**	**43,255**	**437**	**632**	**674**	**533**	**419**	**209**	**66,551**	**153,596**

Research results.

Note: MA (Maranhão), PI (Piauí), CE (Ceara), RN (Rio Grande do Norte), PB (Paraíba), SE (Sergipe), PE (Pernambuco), AL (Alagoas), BA (Bahia).

[13] The crop coefficient was estimated on the municipal level by MMA (2011) and the coefficients for sugar cane were check in face of studies from Biswas (1988), Doorembos & Kassan (1979), Silva et al. (2011), Souza et al. (2012), Carmo (2013). No simulation results diverged substantially from the results presented by these authors, especially presented from the ones presented by Carmo (2013), which considered the semi-arid region of Bahia for the analysis of the crop cycle.

[14] SCEN 1 was used in the comparison for being the scenario of greater impact on water resources.

For instance, the states of Maranhão, Piauí, and Bahia are the states of greater expansion in irrigated agriculture for the region. The potential for expansion would reach more 268,152 and 308,941, and 393,859 hectare; the simulation represent 15.24%, 14%, and 16.89% of potential.

The expansion of irrigated area in the state of Alagoas represents 10.23% of the regional potential. However, when considering the irrigated area described in MMA (2011), the policy result would lead to an irrigated area exceeding the potential capacity for the region, and the impact on water resources would be greater than the microregional potential.

The maximum potential of irrigation considered the MIIP class for Brazil would be of 12,938,220 hectares and 1,056,424 in the Northeast area, especially in the states of Bahia, Maranhão, and Piauí. For Bahia state, the expansion would occur in practically all crops, with emphasis on the Other Crops. Bahia offers the most extensive coastline with access to the Atlantic Ocean, and, among the northeastern states, it represents the largest territorial extension, the largest population, and the largest gross domestic product. Then, the water use as police result by state and crop is in table 9.

Table 9. Table presenting water usage by crop, accumulated policy deviation for SCEN 1 in Million m ³.

Crops	MA	PI	CE	RN	PB	SE	PE	AL	BA	Total
Rice	49.58	106.98	0.44	0.15	0.15	0.48	0.60	0.39	567	164.44
Maize Grains	15.50	16.17	0.52	0.11	0.28	0.19	0.03	0.00	9.92	42.72
Wheat and Cereals	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.07
Sugar Cane	73.25	11.01	0.49	5.14	5.29	3.14	0.65	0.86	73.15	172.98
Soybeans	12.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	22.23	34.42
Other crops	15.19	44.65	0.85	0.42	0.29	0.35	1.37	0.07	122.06	185.25
Cassava	23.09	3.40	0.00	0.01	0.00	0.04	0.15	0.15	5.14	31.98
Tobacco Leaves	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.07	0.08
Cotton	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	16.87	16.93
Citrus Fruits	0.35	0.82	0.03	0.00	0.00	0.33	0.10	0.06	2.75	4.44
Coffee Beans	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	27.90	27.91
Veg. Exploration	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	12.20	12.22
Sum	189.14	183.03	2.33	5.85	6.05	4.53	2.92	1.55	298.03	693.43

Research results

Sugar cane and rice crops would expand in Maranhão and Piauí. The regions have presented growth in the production of these crops oriented by regional policies that have been supporting the expansion of these cultures in the states that are major producers of irrigated rice in the northeast of the country, with a planted area of 349.8 and 95.1 thousand hectares in 2014/2015 respectively (CONAB, 2015). Rice in Brazil presents an important social role regarding food safety, and the largest irrigated area lies in the southern part of the country (90% approximately).

The use of water in the "Other Crops" aggregate may not represent the regional peculiarities and implies in the average increase in water use for all crops, which represents a portfolio of agricultural products essential for economic development. The water use in "Other Crops" would be more significant in Bahia and irrigated rice in Piauí.

Ceará state would be relevant in the expansion of irrigated areas to promote regional development. However, the distribution of rainfall that is not homogeneous and some regions present high evaporation and low precipitation and / or irregularity of rains, causing the seasonality and limiting access to water.

The regional water availability has been an obstacle to the expansion of irrigated areas in the Northeast. In this sense, a key point in this study was to know the river flow of basins and sub-basins that supply the Northeastern states of Brazil. This direction is essential for the water supply estimate and since the division of Brazilian watersheds does not present the same geographical boundaries of states. Some states receive water from other river basins that are catchment areas in other regions (states). In other cases, the water catchment area can be the same as that of the supply, which reduces microregional and state water availability, such as, for instance: the basins in the states of Rio Grande do Norte (RN) and Paraíba (PB). Therefore, the flow can be visualized in Figure 4.

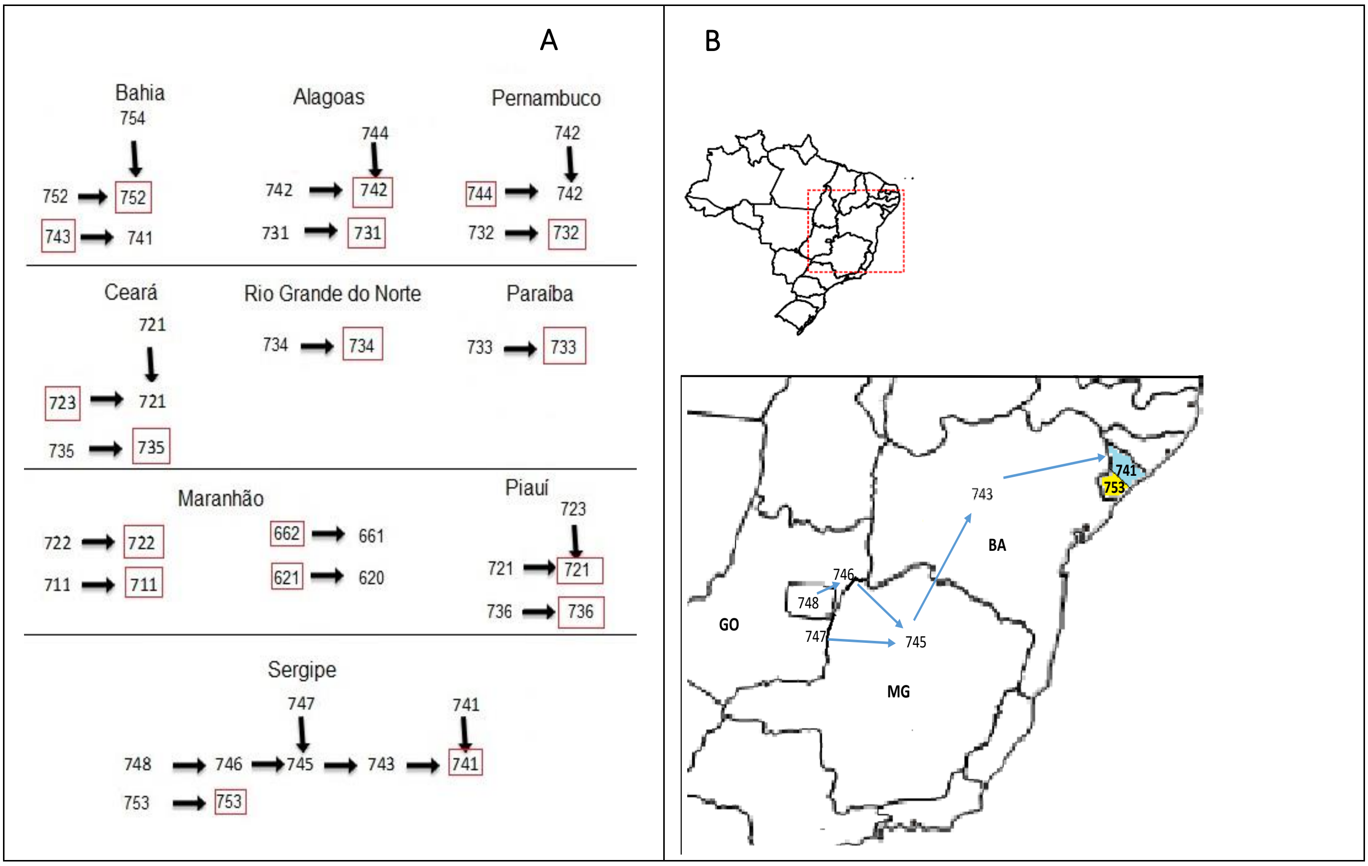


Figure 4. Flowchart of the basins for the states of the Brazilian Northeast region.
Note: The figure illustrates the flow of river basins toward the northeastern states by basin code, and Figure B exemplifies the flow from basins from other state to Sergipe state.

The data from Figure 4 can be best understood through an example. Considering the case of the state of Sergipe, it turns out that it has catchment areas in the states of Goiás (basins 746 and 747), Minas Gerais (basin 745), Bahia (basin 743) and in the Federal District (basin 748). Water surpluses of these areas were computed following the stream and its estimated feeding to the basins 741 and 743, which belong to the state. In order to facilitate te visualization of the stream, the figure 5.B illustrates the particular case of the state of Sergipe. As described above, the same procedure was done for the other states of the Northeast and shows the differences between the water paths (basins) to the states.

The results for the estimated water supply were compared with water availability in terms of average flow as described in ANA (2007). Some differences have been identified, especially for the Parnaíba basin, with a ratio of 2.5. However, in the case of the São Francisco River[15], East Atlantic, and Tocantins-Araguaya, the result is similar to that disclosed by the agency of waters, with differences of 5% for the São Francisco River and East Atlantic. It should be noted that the evapotranspiration and precipitation by microbasin and river may differ between periods, and the evapotranspiration of reservoirs can also impact on the results.

Two river regions were analyzed for the Alagoas state; the São Francisco River basin (742) and the Coastal Eastern NE (731-Atlantic passage North/Northeast). The Coastal Eastern NE (731) presents shorter rivers, many of them occurring within the state or coming from the state of Pernambuco; i.e., the area of contribution is smaller than the area of the São Francisco River (whole). Precipitation in this region is greater than at the portion of the São Francisco River that lies within the State of Alagoas, which generates a water surplus in 731 higher than that of 742. However, consumption in 731 will also be larger because it is the coastal region of the state, where the greatest concentration of population is to be found.

[15] The São Francisco River is one of the most important watercourses in Brazil and South America. In 2017, the state of Paraíba began to receive water from this river in one of the most important water works for the Northeastern region of the country, the transposition of the São Francisco river

Regarding the São Francisco River, the water volume of the river is higher (when the whole of the river is considered). It receives water from Minas Gerais state (Central-Western Brazil). And so, in the case of Coastal Eastern NE/Alagoas region (731), water is consumed and produced in the same region, for there is no surplus above or below. In the São Francisco/Alagoas (742), there is a surplus from other river basins (744 São Francisco River/Pernambuco) that have been contributing to the surplus in this region. However, the average rainfall and the actual evapotranspiration are also higher in the basin 742, part of Alagoas.

In this sense, table 10 presents the estimated consumption for each basins that supply the Northeastern States in the year 2005 and the estimate for 2025, without considering the surplus water from other basins. Note that the F_B_UF column describes the fraction of the basin as considered regarding supply in the State, and the F_C_Basin column for the years of 2005 and 2025 consider the water consumption in the basin in the state in 2005 and 2025 respectively.

The same watercourse delimits some states, such as in the borders of Alagoas and Pernambuco (S. Francisco River). I.e. the sum of surpluses of 742 (Alagoas) + 744 (Pernambuco) might not be sufficient for the water consumption in the region. The water balance calculated the contribution of surplus as state-level, and this contribution can diverge from the literature in terms of watersheds. This problem occurs when establishing a unit that is the mixture of basins and States, which makes it impossible to specify the volume of water generated in the regions, but provides an excellent indication of how water distribution occurs within states.

Table 10. Estimated consumption in the basins that feed the Northeastern States in 2005 and 2025.

			2005		2025	
UF	Basin	F_B_UF	Consumption in the basin	F_C_Basin	Consumption in the basin	F_C_Basin
AL	731	48%	3,585,709,317	51%	3,968,040,328	57%
AL	742	52%	278,028,243	52%	309,144,782	58%
PE	732	29%	1,998,296,711	19%	2,209,048,867	21%
PE	744	71%	606,459,069	36%	688,929,048	54%
RN	734	100%	645,017,617	17%	782,422,124	21%
PB	733	100%	799,835,034	11%	988,024,696	14%
PI	721	99%	245,781,176	1%	472,589,801	1%
PI	736	1%	1,710,931	0%	82,570,734	2%
MA	662	9%	88,061,123	1%	202,945,158	2%
MA	711	71%	277,160,089	0%	474,956,059	0%
MA	722	20%	70,471,685	0%	138,521,749	0%
BA	743	54%	1,318,788,084	5%	2,128,192,947	8%
BA	752	46%	891,072,593	3%	1,313,449,790	4%
SE	741	34%	62,643,129	6%	75,499,218	7%
SE	753	66%	159,623,134	6%	187,666,958	7%
CE	723	11%	67,998,379	3%	82,570,734	3%
CE	735	89%	822,782,282	4%	989,306,925	5%

Results.

For the State of Rio Grande do Norte (RN) and Paraíba (PB), 734 basins (Coastal Eastern NE/Rio Grande do Norte) and basin 733 (Coastal Eastern NE/Paraíba) represent 100% of the basin's share in the State. Rio Grande do Norte State to present a semi-arid climate with low rainfall by its seaside, as well as high temperatures and dry, constant winds.

The hydrography of the Northeast of Brazil is considered intermittent and irregular, that is, many rivers in the region are subject to changes of the semi-arid climate that, in some cases, become perennial or seasonal. The Ceara state presented as a result a low percentage of water usage in relation to water availability. However, basin 735 (Coastal Eastern NE/Ceará), is composed of numerous rivers that are poorly distributed, and the largest volume of rainfall is in the coast region, which causes differences between water supply and demand in the State.

In all Northeastern States, the water volume is not evenly distributed[16]. The interannual and interregional variability of precipitation over the Northeast, both in spatial and temporal scales which diverges at the microregion level and hydrographic basins. The results for Maranhão and Piauí follow the same logic of physical and climatic differences in geo-environmental domains, as described for the State of Ceara. However, in the cases of Maranhão and Piauí, the high percentage of groundwater supply makes an impact over regional supply[17].

When considering the surplus from other basins, the primary change in the results would occur in the states of Alagoas and Pernambuco, where the consumption and surplus ratio would be attenuated due to the positive result (surplus less consumption) from other regions. In SCEN 1, consumption in the Alagoas would be of 50% of the water availability, reaching up to 26% in Pernambuco. Note that water availability, even without considering climatic factors, changes between periods due to the flow of surpluses that changes in each basin .These results can be viewed in table 11.

Table 11. Water supply[18] and demand for the Northeastern states in 2005 and 2025 (SCEN 1).

UF	2005 (in Million m³)			2025 in SCEN 1 (Million m ³)		
	Water supply	Water Demand	Ratio %	Water supply	Water Demand	Ratio %
AL	8,611	3,864	45%	8,528	4,277	50%
PE	10,371	2,605	25%	11,060	2,898	26%
RN	3,802	645	17%	3,802	782	21%
PB	7,306	800	11%	7,306	988	14%
PI	41,260	247	1%	41,177	476	1%
MA	161,992	436	0%	162,107	816	1%
BA	39,297	2,210	1%	38,644	3,141	8%
SE	96,375	222	0%	88,633	263	0%
CE	56,240	891	2%	18,597	1,072	6%

The result of the interaction between supply and demand.

The simulation show that the expansion would promote an increase of water in the Tocantins-Araguaia hydrographic region (97%). This hydrographic region also supplies part of the state of Mato Grosso (basin 673) and the state of Goiás (basins 664,674 and 670). These two states (Mato Grosso and Goiás) are located in other regions in Brazil, which according to the PNRH are feasible the expansion of irrigation. The Northeastern Atlantic Hydrographic Region should also present a high increase in the use of water in CEN 1. This hydrographic region is the main supply region of the states of Maranhão and Pará (Northeastern), indicating a high potential for expansion for the irrigation, the increase in this region would be 94%.

The Eastern Northeast Atlantic region is the region that offers the least potential for expansion in water use among the hydrographic regions that supply the Northeast of the country. The results showed that this hydrographic region, which supplies Alagoas (basin 731), Ceará (basin 735), Paraíba (basin 733), Pernambuco (basin 732), Piauí (basin 736) and Rio Grande do Norte (basin 734) Is the region that requires greater attention in irrigation expansions.

Thus, table 12 shows the consumption in 2005 and 2025 for each hydrographic region.

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[16] Described in Noble and Shukla (1996), Molion and Bernardo (2000), Noble et al. (2006), Polzin and Eschweiler-Hastenrath (2014), Barbosa and Kumar (2016)

[17] About 78% of the supply of Piauí is composed of groundwater (ANA, 2010).

[18] The term offer used herein reflects the surplus of water basins and rivers considered within the CWB method for the country's surface water country. The results of supply and demand do not take climate change into account.

Table 12. Water used distributed to the hydrographic regions under analysis in 2005 and 2025. SCEN1.

Hydrographic regions	Usage in 2005 (Mm ³)	Usage in 2025 (Mm ³)	Increase in consumption (%)
Tocantins-Araguaya Hydrographic Region	2,447	4,826	97%
Western Northeast Atlantic Hydrographic Region	363	705	94%
The Parnaíba River Hydrographic Region	384	694	81%
Eastern Northeast Atlantic Hydrographic Region	7,853	8,940	14%
São Francisco River Hydrographic Region	4,119	5,946	44%
East Atlantic Hydrographic Region	1,830	2,488	36%
Southeast Atlantic Hydrographic Region	14,030	16,071	15%
The Uruguay River Hydrographic Region	2,910	3,752	29%

Results of the model.

It should be noted that the comparison of water demand exclusively by water availability in the region does not, in its amplitude, describe the regional potential for the expansion of irrigated agriculture. Regional climate and hydrogeological heterogeneity in the Northeast demand new research. Surplus flows showed how Northeastern states are dependent on basins located outside the northeastern region, such as the São Francisco River. Changes in water use in some basins that are catchment areas in others regions will impact on the volume of water that flows into the Northeast.

Final considerations

The model results suggest that the expansion of irrigated area, especially in the North and Midwest regions, are plausible options in all scenarios. Crops of sugar cane, rice and other crop products (including fruits) will to benefit the most from this expansion. The scenarios described in PNRH consider regional water availability in all situations.

The most noteworthy effect over water demand would happen regarding sugarcane crops, which, with an increase to 549.342 irrigated hectares, would raise the demand for water in 2,940 million m³, being the culture that would elevate water demand in Brazil to the highest standards, followed by that of irrigated rice, with 1,808 million m³ of water. In regional terms, the expansion in the State of Mato Grosso (+612,380 hectares) would raise in 92,56% the water usage in the State.

In fact, the climate and hydrogeological regional heterogeneity, including exploitation and activity risks, requires oriented microregional research. The Northeast region was the region with the smallest expansion of irrigated area in three simulated scenarios. However, the impact over water resources in this region is noticeable, especially in Alagoas and Pernambuco state, i.e., the water demand required to contemplate the whole cycle of irrigated crops in the Northeast, plus the populational growth associated with the productive advance, would require increased availability of water basins, which may not be consistent with the future water supply.

As an important limitation of the results of this study, attention should be drawn to the fact that the analysis of water availability is restricted, in fact, to the regions served by the basins. That is, there are important regions of inland Northeastern states that are not affected by the basins under analysis, or else where the balance at microregional level can be very different and possibly insufficient. This is the case, for example, of the Northeasters semi-arid region and of the region known as the "Drought Polygon," a region that covers 1,348 municipalities that are subject to prolonged periods of drought, and strong restriction in water supply, composed of geographical areas with different levels of dryness. Our model, however, is not sufficiently region-specific to encompass these cases.

These limitations, if on the one hand show the difficulty of working with the theme of water supply in a country as large as Brazil, on the other hand points out the direction future research efforts in the area could take, since the related uncertainties are obstacles to the operational planning and management of natural resources. In future studies we suggest the inclusion of information on climate change and on the discharge level changes of rivers in the Northeastern states.

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