An Empirical Analysis of the Power Structure and Optimization of Water Allocation in the State of Ceará, Brazil

Tara DePorte, Columbia University, MA Climate and Society
Data Analysis and Methodology: Tara DePorte and Abigail Tinker

Introduction

The State of Ceará is located in the Northeast of Brazil and is considered one of the most densely populated semi-arid regions in the world. With an estimated population of 7.1 million people, of which 39% percent reside in the capital city of Fortaleza[1], there are many sectors competing for limited water resources, including municipal (human consumption), industry, agriculture, fishermen, and ranching. There has been a large push from the state government behind the recent growth in industry and tourism, which has centered predominantly around the Fortaleza Metropolitan Region. Of the 48% total rural population, 79% are employed in the agricultural sector[2], however, many of these farmers do not currently have access to formal water resource infrastructure and are rain fed agriculturalists. The climatic variability of the region and subsequent history of multi-year droughts has made water resources, their allocation and management a forefront issue in social, political and economic issues of the region and the State.

With pressures from the federal government and international funding agencies such as the World Bank, there has been a trend in the past 30 years towards the decentralization of water resource management throughout Brazil. Within the state, this has meant a dramatic increase, and focus on, hydrological infrastructure development, including reservoir and canal systems. In addition to this, there are many statewide and regional approaches to water management and allocation, including the creation of Water Allocation Committees on the river-basin level, which are responsible for bi-annually determining the release of waters from regional reservoirs for the rural population and associated sectors.[3] In this paper, we examine more closely the power structure of the Jaguaribe River Basin Water Allocation Committee and the relative amount of decision-making power representative groups has within the Committee. In 2003, the Jaguaribe River Basin Water allocation Committee was composed of 107 member from the four sub-basins of the River (Baixo Jaguaribe ,Alto Jaguaribe, Banabuiu, Medio Jaguaribe), in which representation was divided as follows:

- *30% of members are representatives of civil society i.e. diverse rural workers unions and associations of inhabitants; among these, the most highly represented group is the rural workers unions (2/5 of total);*
- *28% public and private water users, e.g. companies providing water for human use, associations of producers from both public and private irrigation areas, and other associations;*
- *25% representatives of municipal governments, i.e. ,prefeituras (municipal executives). Secretariats of municipal government, and camaras municipais (municipal legislative);*
- *17% representatives of the various state and federal government agencies, i.e. people from DNOCS, COGERH, EMATERCE, SEAGRI, and CHESF.* [4]

It is important to note that although the state has instituted a participatory management and allocation structure for rural sectoral water usage, the allocation of water to the Fortaleza

[1] Governo do Estado do Ceará, 2000b
[2] Data as of 1999
[3] The Committees meet in January and July, in the beginning and end of the rainy season, respectively.
[4] Quoted from Taddei et al, "Integrating Climate and Water Management in Ceará: Historical Background, Social and Legal Structures, and Implications", pg. 24.

Metropolitan Region continues to be controlled solely by COGERH (Companhia de Gestão de Recursos Hidricos do Ceará), the State's agency for water resources management. This dichotomy in water management structure is indicative of the inequity in resource allocation to the metropolitan region, which simultaneously serves as the center of economic output (85% of the State's GDP[5]) and the industrial sector of the State, and the rural populations, which are the majority of the total population, however underrepresented economically speaking. This issue is key to social and political systems within the state and nationally, in that the population of Ceara are considered among the poorest in all of South America. In the following sections, we calculate and analyze sectoral minimum needs to estimate allocation of water resources to the participating sectors, based on a variety of "priority statuses" for each.

Although the agricultural sector of the State of Ceara only represents 7% of the total GDP, approximately 2.69 million people, or approximately 26% of the State's population, are employed in agricultural activities[6]. Therefore, the crop productivity and water needs are imperative to the livelihoods of many, particularly in the face of climate variability. Therefore, after looking into the structure of the Water Allocation Committee and total sectoral water allocation for the State, we take a closer look at the agricultural sector to help better understand the dynamics of the primary production crops of the region and their subsequent values and water needs. This is meant to serve as a tool for the optimization of crop and land-use productivity in the face of water pressures.

This project serves as a preliminary analysis of the previously mentioned variables. We hope that the structure and analysis methods outlined and applied in this paper will serve as a tool for further analysis and incorporation of raw data and an increase in the complexity of the variables and contributing factors of water allocation in the State of Ceara and other regions.

Data Analysis and Methodology

The methodology used to analyze the Committee structure and decision-making power (specifics of which will be discussed in the following section: *Using the Shapley Value Game Theory Method to Analyze Voting Structure of Water Allocation Committees in the State of Ceará, Brazil*) is meant to take into consideration the potential difference between representation in participatory decision-making and the strategic value of each voting coalition's vote. In addition to game theory analysis of the Water Allocation Committee, we constructed a simple optimization model to represent estimate allocation of water resources to the participating sectors, based on a variety of "priority statuses" for each, which will be described in the section: *Sectoral Water Use in Ceará*. Finally, we constructed another simple optimization model, coupled with graphs of primary crops hectare coverage, productivity, value, and water needs, to better understand the specific variabilities within the agricultural sector and the financially based optimization of rural water resources. The specifics of this model and associated assumptions made are described in *Agricultural Sector Water Withdrawals Optimization Model and Data Analysis.*

.

Using the Shapley Value Game Theory Method to Analyze Voting Structure of Water Allocation Committees in the State of Ceará, Brazil

The Shapley Value method was used to analyze the structure of the Jaguaribe River Basin Water Allocation Committee and the relative power of potential coalitions of voters. The Shapley Value is, "a reflection of the relative number of times that a given player performs the swing vote to make one coalition win out over all others . . . this is an indication of the strategic

[5] Governo do Estado do Ceará, 2000b

[6] Estimates calculated using census data from Governo do Estado do Ceará, 2000b.

value of [each coalitions] vote."[7] To compute a relative value for each player under different majority rules, we used the following formula:

$$\phi_i(V)= \phi_T(t-1)!(n-t)!/n!$$

ϕ is the Shapley Value of the individual player i under the majority voting rule V, T = the total number of winning coalitions in which player i can be the deciding vote, for each of those coalitions n=number of players in the game, t=number of players the individual coalition are used to determine a value which is summed with the value for all coalitions in which i is the deciding (winning vote) to arrive at the Shapley Value.

Example – Company Stockholders
Player 1: has 10 shares = 10 votes
Player 2: has 20 shares = 20 votes
Player 3: has 30 shares = 30 votes
Player 4: has 40 shares = 40 votes

Under simple majority rule voting (V=51% voting rule) the total possible winning coalitions are:
{2,4}, {3,4}, {1,2,3}, {1,2,4}, {1,3,4}, {2,3,4}, and {1,2,3,4}
For Stockholder 1 the only winning coalition, which would not win without her vote, is {1,2,3}. n=4, the number of players in this coalition is 3 (t=3), therefore the Shapley Value is computed as:

$$\phi_1(51\%) = (3-1)!(4-3)!/4! = 1/12$$

For Stockholder 2 the winning coalitions such that they are losing coalitions with out 2 are {2,4}, {1,2,3}, and {1,2,4}. The Shapley Value for stockholder 2 is then:

$$\phi_2(51\%) = (2-1)!(4-2)!/4! + (3-1)!(4-3)!/4! + (3-1)!(4-3)!/4! = 3/12$$

For Stockholder 3 the pivotal coalitions are {3,4}, {1,2,3}, and {1,3,4}, the Shapley Value for player 3 is:

$$\phi_3(51\%) = (2-1)!(4-2)!/4! + (3-1)!(4-3)!/4! + (3-1)!(4-3)!/4! = 3/12$$

Finally Stockholder 4, with its 40 votes, is the deciding vote in 5 coalitions, {2,4}, {3,4}, {1,2,4}, {1,3,4}, and {2,3,4}:

$$\phi_4(51\%) = (2-1)!(4-2)!/4! + (2-1)!(4-2)!/4! + (3-1)!(4-3)!/4! + (3-1)!(4-3)!/4! + (3-1)!(4-3)!/4! = 5/12$$

The information is notated the following way:
Player (1,2,3,4)
Vote Strength (10,20,30,40)
Shapley Value (1,3,3,5)
This shows that the relative vote strength and the relative value diverge.

2003 Jaguaribe River Water Allocation Committee – 107 Members

Game 1 – Current Water Board Assuming Sectoral Coalitions
Info/Assumptions: the current make up of the water board breaks down into 4 categories of participants, we assume that each category has similar interests and votes as a coalition.

Player 1: Civil Society – 30% = 32 votes
Player 2: Public and Private Water Users- 28% = 30 votes

[7] Peter Rogers, "How Not to Constitute a Water Board," July 1, 1989

Player 3: Municipal Government Reps – 25% = 27 votes
Player 4: State and Fed Government Reps – 17% = 18 votes

51% Voting Rule	*75% Voting Rule*	*83% Voting Rule*
Players (1,2,3,4)	Players (1,2,3,4)	Players (1,2,3,4)
Vote Strength	Vote Strength	Vote Strength
(32,30,27,18)	(32,30,27,18)	(32,30,27,18)
Shapley Value (4,4,4,0)	Shapley Value (5,5,1,1)	Shapley Value (4,4,4,0)

Game 2- Entire Population Broken into Urban, Rural, and Other Municipalities
Info/Assumptions: According to the Governo do Estado do Ceara, 2000b, the state population is approximately 7.1 million. In the following game theory, it was assumed that the entirety of the state population has access to and allocation of water resources governed by the water board, however, which would be representative of the optimum goals of the water resource infrastructure development of the State (100% access to water resources). ; the population is represented proportionally and these representatives break into 3 coalitions based on the categories of where they live: Fortaleza, in other municipalities, or in the rural areas.

Player 1: Fortaleza – 39% = 42 votes
Player 2: Rural – 48% = 51 votes
Player 3: Other Municipalities – 13% = 14 votes

51% Voting Rule	*75% Voting Rule*	*83% Voting Rule*	*88% Voting Rule*
Players (1,2,3)	Players (1,2,3)	Players (1,2,3)	Players (1,2,3)
Vote Strength	Vote Strength	Vote Strength	Vote Strength
(42,51,14)	(42,51,14)	(42,51,14)	(42,51,14)
Shapley Value	Shapley Value	Shapley Value	Shapley Value
(4,4,4)	(6,6,0)	(6,6,0)	(4,4,4)

Game 3 – Current Water Board Assuming Sub-Basin Regional Coalitions
Info/Assumptions: The Jaguaribe River Basin, over which the Water Board presides, has 4 sub-basin regions. It has been noted that voting coalitions are often drawn along geographical lines, we assume that the people within a sub-basin share the same interests. For example the downstream group may favor release of a lot of water for irrigation purposes whereas the group that live above the reservoir may favor leaving the reservoir level high (lower release level) so that their fishing potential is better. People from the Baixo Jaguaribe sub-basin represent 36% of the current water board members[8].We assume that the other three regions equally share in the rest of the representation (21% of the rest of the members each). We examine how the larger representation from Baixo Jaguaribe affects power under different voting rules.

Player 1: Baixo Jaguaribe – 36% = 38 votes
Player 2: Alto Jaguaribe - 21% = 23 votes
Player 3: Banabuiu - 21% = 23 votes
Player 4: Medio Jaguaribe – 21% = 23 votes

[8] Taddei et al, p. 24.

51% Voting Rule
Players (1,2,3,4)
Vote Strength
(38,23,23,23)
Shapley Value (6,2,2,2)

75% Voting Rule
Players (1,2,3,4)
Vote Strength
(38,23,23,23)
Shapley Value (6,2,2,2)

83% Voting Rule
Players (1,2,3,4)
Vote Strength
(38,23,23,23)
Shapley Value (3,3,3,3)

Results and Analysis of the Voting Structure of Water Allocation Committees

It is important to note in the analysis of the Shapely Value results that the *actual* voting procedure of the Jaguaribe Water Allocation Committee is currently consensus-driven. However, the Shapely Value analysis is still relevant in that it shows how the decision-making power of the members would change in the face of Committee changes, which is particularly applicable due to the relative newness of the participatory management approach. Furthermore, the results of the analysis may give some insight into why the committees were formed under consensus vote, why members are represented in the current percentages, and the potentials for change in Committee that would give more power to the marginalized societies. it can be assumed that In Game 1, where it was assumed that there was a simple majority rules vote (51%) and the Jaguaribe Water Allocation Committee was composed according to the 2003 meeting percentages, it was shown that, although the state and federal government agencies would have *no strategic value*. Interestingly, this was equally true for the 83% voting rule assumption. In the case of a 75% voting rule, both the state and federal government agencies as well as the municipal representatives had 80% less voting power than civil society and public/private users. These results indicate some of the motivations for federal, state and municipal representatives support of consensus-based voting rules in which they have an equal, if not greater strategic value (due to knowledge-base, access to meetings, and other constraints) than the other groups represented. Furthermore, this shows how although consensus voting would appear to be the most “democratic” means of voting, that the more marginalized groups, including civil society, would have greater strategic value if the current Committee makeup was changed to either a simple majority-rule or 83% voting rule.