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How do people gain access to water resources in the Brazilian semiarid (Caatinga) in times of climate change?

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Abstract Climate change is becoming an imminent reality, especially in arid and semiarid regions. Therefore, it is essential to understand the relationships between humans and aquatic ecosystems in order to devise efficient management and conservation strategies. We conducted 126 interviews using a semi-structured form to record water sources, transport strategies, and the use and treatment of water by communities surrounding four reservoirs within two drainage basins in the semiarid region of Brazil. These factors were then compared to the mean water volumes of the respective reservoirs from 2013 to 2015, a period of severe drought in that area. Seven types of water sources were considered, according to the perspectives of the interviewees: large reservoirs (dams) (43% of the citations), other smaller reservoirs (25%), rainwater (17.5%), wells (7%), waterholes (3%), bottled water (4%), and water tanks (0.5%). The water resources obtained are transported to human residences in seven different manners: actively pumped (34% of the citations), by water tanker truck (33%), distributed in pipes by local resident associations (11%), transport by animal (14%), human transport (4%), by car (2%), and by motorcycle (2%). The water is then used for domestic purposes (21%), for personal hygiene (20%), by animals (19%), in agriculture (18%), for cooking (10%), for fishing (7%), and for drinking (6%). A worrisome trend was that many local residents did not treat the water they were consuming. Climate change affects seasonal patterns of rainfall that will, in turn, determine the availability and quantities of water resources, provoking changes in the sources of water used by human populations, their strategies of access to that resource, and water-use patterns. It is necessary sustainable use of water resources based on the realities of local populations.

Keywords Water scarcity · Human ecology · Water resources · Global warming

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Introduction

Water is a fundamental resource for human survival, and many different strategies have been developed to obtain it and utilize it for industrial, agricultural, and domestic purposes (Haddeland et al. 2014). The construction of reservoirs has been one of the traditional methods of storing water for future use and establishing urban and rural populations in otherwise inhospitable areas—thus increasing the adaptive reach of our species. Nonetheless, aquatic ecosystems, even artificial systems, are threatened as problems related to water resource availability increase due to climate change and unsustainable use patterns (Grafton et al. 2013).

Global climate change is expected to disproportionally affect semiarid regions, where overall precipitation is low and its distribution irregular. Increases in average temperatures will cause the degradation of natural resources and the quality of human life through prolonged droughts and consequent water resource scarcities (Feng and Fu 2013; Elliott et al. 2014). The availability of this precious natural resource is already at its limit in some areas, and worsening weather conditions will cause socioeconomic stress, including crop failures, unemployment, asset erosion, decreases in income, and poor nutrition (Singh et al. 2014). An example of this situation can be seen in the semiarid region of Brazil, where population growth, land use changes, and increasing demands for quality of life improvements endanger natural resources (Magalhães et al. 1988), with natural climatic variability eroding the social and economic well-being of the majority of its population (Gaiser et al. 2003).

As such, the construction of reservoirs in the semiarid region of Brazil appeared as a solution to mitigate the effects of periodic droughts (Araújo 2003). Reservoirs have since become part of the local landscape and culture, and have important social, economic, and ecological roles (Tundisi et al. 2008; Robock 2012; Lima et al. 2012). During long periods of drought, these reservoirs tend to dry up, however, and water quality decreases, principally due to extremely high levels of regional evapotranspiration (Araújo 2011) with consequent increases in nutrient concentrations that drive cyanobacterial blooms (Bittencourt-Oliveira et al. 2014)—forcing local populations to alter their strategies for obtaining water (e.g., Aquino and Lacerda 2014).

Only 32% of rural residences in the semiarid zone of Brazil received treated water in 2012, while 68% of the population was forced to resort to alternative sources of water (Brazilian Institute of Geography and Statistics, IBGE 2015), such as by drilling or digging wells. This situation becomes quite grave during periods of prolonged drought, which have occurred frequently in recent years, and the semiarid zone of Brazil is currently experiencing the greatest drought in the last 50 years that initiated in 2012 (World Meteorological Organization, WMO 2015).

In times of climate change, it is essential to know the sources, management, and use of water so that management and conservation plans can be developed. In considering that humans are intrinsically dependent and interacting with aquatic ecosystems, or directly with water, they need to actively participate in management and conservation, especially in the local context. In this sense, the knowledge, innovations, and practices of local communities must be added to the management systems (Xu et al. 2014; Gavin et al. 2015; Premauer and Berkes 2015; Silva and Santos 2017). A participatory management model can help in understanding the position adopted by communities in relation to water resources. Participatory management considers the involvement of stakeholders in a collective learning process, which in a cyclical way changes the way people think and act, thus those involved initiate and continue the process of change (Tippett et al. 2005). It should focus on human development, respect local knowledge, promote community empowerment, focus on social justice, enable partnership and dialogue among stakeholders such as government institutions, NGOs, and funding agencies (Warner 1997). A model of participatory management, regardless of the form adopted, is a unique opportunity to change management practice in river basins and to develop more sustainable management practices (Tippett et al. 2005).

In light of this situation, the present study examined how communities in the semiarid Caatinga domain of Brazil have diversified their strategies for obtaining, transporting, and using water under conditions of prolonged drought. We sought to evaluate if the forms of water transport and use by human communities were related to decreases in the available volumes of water in the reservoirs nearest them. We also investigated if that water was treated before being used. Our study aimed to generate data that may help in the future to develop plans for the participatory management and conservation of reservoirs and other water sources in semiarid areas.

Methods

Study area

The study area was centered in the semiarid region of northeastern Brazil, which covers approximately 970,000 km^2. The regional climate is characterized by mean annual temperatures above 20 °C; annual rainfall rates varying from 280 to 800 mm (Pereira-Junior 2007). The annual evapotranspiration rate is greater than the precipitation rate, and the rainy season is concentrated in only 3 to 4 months of the year (Araújo 2011; Alvares et al. 2013).

Fieldwork was undertaken in four municipalities in northeastern Brazil, two of them in Paraíba State and two in Rio Grande do Norte State. The communities studied in Paraíba State were located near the Poções in the municipality of Monteiro (7°53′33″S × 37° 0′32″ W) and the Sumé reservoir in the municipality of the same name (7°40′15″ S × 36°54′26″ W); both reservoirs are part of the Paraíba River watershed. The communities studied in Rio Grande do Norte State were located near the Traíras reservoir (6°30′53″S × 36°55′59″ W) in the municipality of Jardim do Seridó, and near the Sabugí reservoir (6°39′11″ S × 37°12′21″W) in the municipality of São João do Sabugí; both reservoirs are part of the Piranhas-Assú River watershed (Fig. 1).

Volume data of the reservoirs

The volume data of the Poções and Sumé reservoirs were obtained from the Executive Agency of Water Management of the State of Paraíba (EASA 2016); volume data for the Traíras and Sabugí reservoirs were obtained from the Secretariat of Environment and Water Resources of the State of Rio Grande do Norte (SEMARH 2016).

Sampling design and data collection

Information was acquired from local residents through semi-structured interviews and the use of a semi-structured questionnaire with questions related to the sources of water utilized, strategies of water transport, water uses, and water treatment. We visited all of the residences located up to 150 m from each reservoir during the months of September and October 2015. At least one individual in each residence was interviewed, preferably heads of household (male or female) totaling 126 individuals (38 near the Poções reservoir, 22 near the Sumé reservoir, 31 in Traíras, and 35 in Sabugí).

Most of the individuals interviewed were males (64.3%, $n = 81$), women represented 35.7% ($n = 45$) of the interviewees. Age ranged from 18 to 82 years (51.1 ± 14.14). Of the interviewees were illiterate, 60.3% ($n = 76$) did not complete elementary school, 3.2% ($n = 4$) did not complete high school, 3.2% ($n = 4$)

Fig. 1 Location map of the communities and reservoirs surveyed, hydrographic basins of the Paraíba River and Piranhas-Assú River, Brazil

had completed secondary education, and 1.6% ($n = 2$) had completed high school. The majority of respondents were farmers (70%, $n = 88$), 16% ($n = 20$) fishermen, 6.3% ($n = 8$) home caregivers, and 7.7% ($n = 10$) public workers. The residence times near the reservoirs ranged from 1 to 81 years (25.80 ± 18.40). His average income was R $ 735.71 (equivalent to approximately US $ 236.00).

Ethics statement

The objectives of the study were explained in detail to the interviewees before each interview. Similarly, we obtained their permission to record their responses and images by way of signed consent forms. Ethics approval for the research project was granted by the Ethics Committee of the State University of Paraíba—UEPB, Brazil (process no. 1.030.872).

Data analyses

Data concerning the water sources, strategies of water transport, and use of reservoir water was recorded on a presence/absence matrix. Information concerning water treatment was characterized in classes, and the data matrix was log $_{(x+1)}$ transformed. All of the matrices were subsequently transformed into Euclidian distance coefficients for posterior analysis.

All of the analyses were based on information concerning the years 2013 to 2105, although we chose to graphically present the significant decrease in water volumes in the reservoirs between the years 2012 and 2015. The correlations of the percentage volumes of the reservoirs, the forms of transport, and water uses with the median water volumes of the reservoirs were examined using Pearson's correlation coefficient ($r = 0.5$).

Permutational analysis of variance (PERMANOVA) was used to determine the existence of different sources of water, transport strategies, and water uses among the different communities (Anderson 2001; Anderson et al. 2008), using 9999 permutations, considering one factor (reservoir) and four levels (the Sumé, Poções, Traíras, and Sabugí communities). Post-hoc tests were used to compare variations in the sources of water, transport strategies, and water uses among the four levels considered. The percentages of the reservoir sources, the forms of transport, water usages, and water treatment were calculated to construct bar and line graphs.

With the exception of Pearson's correlation analysis, which was run using Bio Estat 5.0 software (Ayres et al. 2007), all of the statistical analyses were performed using PRIMER-6 + PERMANOVA software (Systat Software, Cranes Software International Ltd., Anderson et al. 2008).

Results

During the study period, all four reservoirs demonstrated accentuated losses of water volumes, beginning with mean volumes of 13.6% (Poções), 29.3% (Sumé), 18.4% (Traíras), and 13.6% (Sabugí) in 2013, but terminating 2015 with mean water volumes of 2.4% (Poções), 16.4% (Sumé), 2% (Traíras), and 6% (Sabugí) (Fig. 2).

Seven types of water sources identified and used by local residents were recorded: (1) the reservoirs themselves (with dams), (2) other smaller reservoirs, (3) rainwater, (4) well water, (5) waterholes (*Cacimba*), (6) water tanks (*barreiro*), and (7) commercial bottled water, as follows:

1. Reservoirs

   Reservoirs are artificial ecosystems (Fig. 3) formed by interrupting the free flow of water in a river by means of a dam. In the present study, the rivers were dammed to construct four reservoirs that collect water during the rainy season.

   During the periods of greatest water volume in the reservoirs, they served as the principal sources of water for the surrounding communities, as could be observed in statements made during the interviews:

> "Since 2012 there's no water. When there's water, it's used for everything ..." (Resident living near the Traíras reservoir).

Under drought situations, as recorded during the research period (2015) when reservoir water volumes are extremely reduced, local residents must depend on other sources of water. As reservoir water volumes become reduced, water quality diminishes, as does the distance to which one must travel to alternative water sources. Some residents, due to a lack of options, must continue to use water from the greatly reduced reservoirs for drinking and cooking—in spite of its poor quality. This situation was recorded for residents near the Poções and Traíras reservoirs

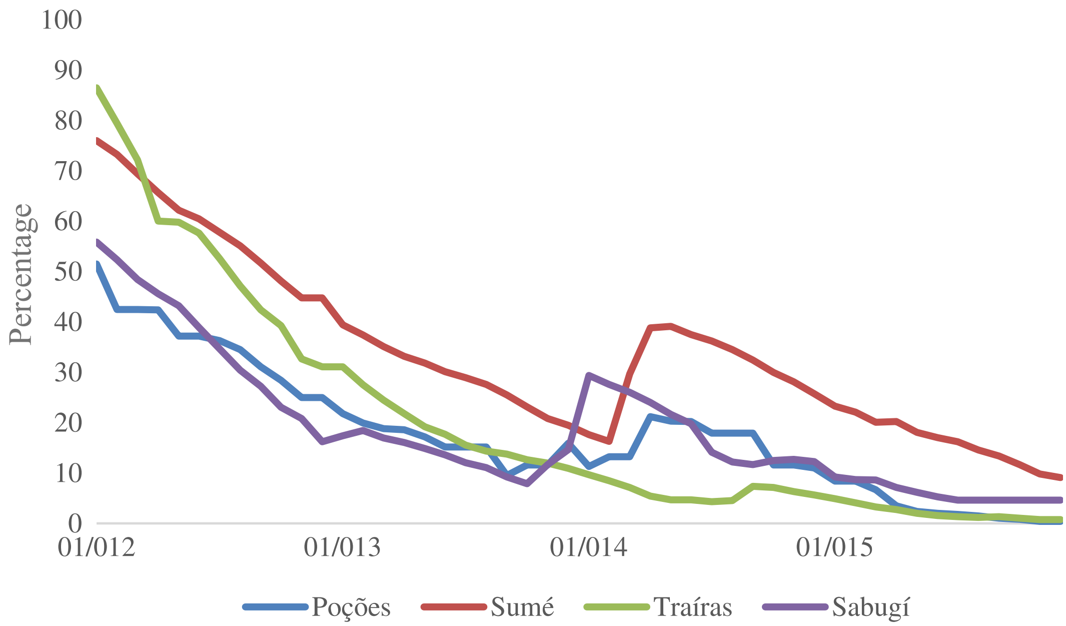

Fig. 2 Evolution of the water volume of the reservoirs surveyed during the years 2012 to 2015

(6.35%, $n = 8$) that contained only green water (Fig. 4) in much reduced volumes (mean volumes of 2.4 and 2%, respectively).

2. Other smaller reservoirs

   Smaller reservoirs (Fig. 5) are called "*açudes*." Local residents distinguish between the larger reservoirs near where they live from these smaller holding tanks, considering the larger ones (government constructions) "*barragems*" (dams) while calling the smaller ones (generally constructed independently) "*açudes*" (although this name is also frequently used to designate large reservoirs). Smaller reservoirs ("*açudes*") experience less water use pressure than the principal reservoir (*barragem*) and can sometimes hold satisfactory volumes even during prolonged dry periods. *Açudes* are constructed along smaller watercourses, not in the beds of principal rivers, and invariably employ less elaborate construction techniques (usually just downstream earthen walls).

3. Rainwater

   Rainwater is collected throughout the dry lands (Fig. 6) as it flows off roofs and is collected by gutters, and then stored in cisterns. The residents usually let the first rains pass (often three) before collecting and storing the rain water, as a way of cleaning the roofs and gutters. After the roof is "clean," tubes are connected to the gutters and the rainwater directed to the cisterns. Cisterns are lined using bricks or concrete plates in excavations that are generally circular or square. Rainwater stored in

Fig. 3 Traíras reservoir at the beginning of sampling, Piranhas-Assú river basin, Rio Grande do Norte, Brazil

Fig. 4 Photograph *1* shows the Traíras reservoir, and photograph *2*, the water of the reservoir itself, municipality of Jardim do Seridó, semiarid region of Brazil

cisterns is considered to be of high quality, and is therefore used almost exclusively for essential purposes such as drinking (principally) and cooking.

4. Wells

   We encountered wells (Fig. 7) that had been dug manually as well as drilled. Hand-excavated wells are generally encased by masonry or by concrete tubes. They are generally located directly within reservoirs/ponds, and are thus covered by water when those bodies are full. This represents a human adaptation to seasonally dry conditions, as when the water reservatories are full there is no access to the well—but when water levels drop, the residents have access to subterranean reserves. When the cistern at a residence dries out, well water is used to supply all primary household necessities. Other alternative sources of water are employed for secondary purposes, such as washing dishes, bathing, and watering animals.

5. Waterholes (*Cacimba*)

   Watering holes are generally excavations made in lowland sites such as swamps, with no specific structure to contain the waters, being only wide and moderately deep excavations (with irregular outlines) known as "*cacimbas*" (Fig. 8). Water flows into those waterholes from the groundwater table, locally known as "*olhos d'água*" or "*veias d'água.*" The groundwater flows in through the soil and is thus naturally filtered, so that the water provided by water holes is considered noble and clean—being principally used for drinking and cooking. Local residents indicated that they filter this water through pieces of cloth to remove macroscopic impurities.

6. Water tanks (*Barreiro*)

   Water tanks are excavations made in depressions in the ground, with earthen barriers to reduce surface flow (and loss) of the water (Fig. 9). This type of excavation accumulates water that runs off the land or flows down small, often intermittent, streams. These water reserves are smaller than dam reservoirs or "*açudes*." The water from water tanks is primarily for household use (locally called "*água de gasto*"—water-to-be-used) such as washing dishes and clothes, and not primarily for drinking or cooking because this water will contain impurities washed off the land. Under critical conditions, however, this

Fig. 5 Reservoir used as an alternative source of water, community around the Sabugí reservoir, Piranhas-Assú River basin, semiarid region of Brazil

Fig. 6 Use of cisterns for storing rainwater near the Sabugí reservoir (Rio Grande do Norte), semiarid region of Brazil

water ends up being used for all household necessities.

7. Commercial bottled water

   Bottled water is normally sold in 20 L volumes, specifically destined for drinking, although other uses can be made of it, of course, depending on the availability of water derived from the other sources cited above.

Choices of water sources

The water sources described above were all utilized at the research site, depending specifically on the locality and reductions in the water volumes in the reservoirs. In general, dammed reservoirs are the most widely used sources of water (43%, no. of citations = 94), followed by other smaller reservoirs (25%, n = 54), rainwater (17.5%, n = 38), well water (7%, n = 15), waterholes (3%, n = 7), commercial bottled water (4%, n = 8), and water tanks (0.5%, n = 1). The communities near the Poções and Traíras reservoirs use large quantities of water from other smaller reservoirs: 35% (no. of citations = 26) and 49% (n = 27), respectively (Table 1).

In general, there were differences in relation to the sources of water utilized among the four communities examined, although post-hoc tests demonstrated the lack of significant differences between the Poções and Sumé reservoir communities, and between the Sabugí × Sumé reservoir communities (Tables 1 and 2).

The residents use water from the large dammed reservoirs closest to their residences when those sources have sufficient volumes of water (r = 0.74), which is reflected in reductions in the concomitant utilization of water from smaller reservoirs (r = −0.75), waterholes (r = −0.32), and water tanks (r = −0.32) (Table 3, Fig. 10).

Water transport strategies

Seven forms of water transport were identified in the focal communities: (1) water distribution through pipes installed by resident associations; (2) mechanical pumping; (3) animal transport (bulls and equines), (4) human transport (in buckets or barrels); (5) by car; (6) by motorcycle; and (7) by tank trucks (locally known as "*caminhão-pipa*") (Fig. 11).

Fig. 7 Photograph *1* shows an artesian well (masonry) and photograph *2*, an artesian well with upper water box, Sabugí-RN reservoirs and Poções-PB, respectively, semi-arid region of Brazil

Fig. 8 Photograph *1* corresponds to a reservoir near the Poções reservoir (Paraíba), and photograph *2* to a reservoir excavated inside the Traíras reservoir, Rio Grande do Norte, semiarid region of Brazil

In general, transport strategy that is most utilized for water is mechanical pumping (34%, no. of citations = 63), followed by tank trucks (33%, *n* = 62), distribution of water through pipes installed by resident associations (11%, *n* = 20), animal transport (14%, *n* = 26), human transport (4%, *n* = 06), by car (2%, *n* = 4), and transport by motorcycle (2%, *n* = 04). The communities bordering the Poções and Traíras reservoirs cited high proportions of water transported by tank trucks (30%, no. of citations = 19; and 43%, *n* = 22, respectively) (Table 4).

There were differences in the transport strategies for water among the different communities, with the exception of the Sumé × Sabugí reservoir communities (Tables 4 and 5). When the water volumes of the reservoirs were still satisfactory, the local populations tended to depend more on mechanical pumping to bring water to their residences (*r* = 0.75), which correspondingly reflected less use of animal transport (*r* = −0.78) (Table 3, Fig. 12).

Reservoir water uses by local populations

We recorded seven use-categories among the communities for water derived from the reservoirs: (1) drinking; (2) cooking; (3) personal hygiene; (4) other domestic uses (such as washing dishes, washing clothes, and flushing toilets); (5) maintaining animals (drinking water for cattle, sheep, goats, equines, birds, dogs, and cats); (6) agricultural use (irrigation); and (7) fishing. In general, the principal use was domestic (21%, no. of citations = 118), followed by personal hygiene (20%, *n* = 115), animal use (19%, *n* = 113), agriculture (18%, *n* = 109), cooking (10%, *n* = 54), fishing (7%, *n* = 35), and drinking (6%, *n* = 33). The water derived from the Poções reservoir was largely used for maintaining animals (22%, no. of citations = 35), while water from the Traíras and Sabugí reservoirs was largely used for personal hygiene: 19% (*n* = 30) and 22% (*n* = 33), respectively (Table 6).

The uses of the water resources from the different reservoirs varying among the different communities, although post-hoc tests indicated the absence of significant differences between the Poções × Traíras reservoirs (Tables 6 and 7). In reservoirs with greater water volumes, the water was principally used for drinking purposes (*r* = 0.88) followed by cooking (*r* = 0.56) (Table 3, Fig. 13).

In terms of water treatment, most of the interviewees (64%; *n* = 80) stated that they did not treat the water, with 16% (*n* = 13) of that number declaring that they did not treat the water because it came from tank trucks, or

Fig. 9 Water tanks (*Barreiro*), the arrows indicate the earth bus that allows the accumulation of water. Record in the surroundings of the Poções community, in the Paraíba River basin, semiarid region of Brazil

Table 1 Water sources used by the communities around the researched reservoirs. Ncit. = number of citations of interviewees, * indicate the absence of citation

	Reservoirs themselves	Other smaller reservoirs	Rainwater	Well water	Waterholes Cacimba	Water tanks	Commercial bottled water
Poções	39% (Ncit = 29)	35% (Ncit. = 26)	13% (Ncit. = 10)	3% (Ncit. = 02)	9% (Ncit. = 07)	1% (Ncit. = 01)	*
Sumé	61% (Ncit. = 19)	*	20% (Ncit. = 06)	16% (Ncit. = 05)	*	*	3% (Ncit. = 01)
Traíras	23% (Ncit. = 13)	49% (Ncit. = 27)	11% (Ncit. = 06)	13% (Ncit. = 07)	*	*	4% (Ncit. = 02)
Sabugí	59% (Ncit. = 33)	2% (Ncit. = 01)	28% (Ncit. = 16)	2% (Ncit. = 01)	*	*	9% (Ncit. = 05)

from resident association sources that regularly added chlorine. A total of 38 interviewees (31%) stated that they treated their own water with chlorine, 2% (n = 2) filtered the water through cloth, 3% (n = 3) used clay filters, 2% (n = 2) decanted their water, while only 1% (n = 1) boiled it.

Discussion

We determined that there were variations among the different communities in terms of their alternative water resources, reflecting the different volumes of water available in the reservoirs nearest their respective communities. When those primary reservoirs had only small volumes of water, community members would use alternative sources, demonstrating that they adapt their behaviors in response to long-term droughts. These behavioral adaptations are certainly related to the long history of droughts in the semiarid region of northeastern Brazil (Gaiser et al. 2003). The continuous exposure to stress provoked by frequent droughts induces behavioral adaptations related to survival and spiritual, cultural and recreational relationships, as well as general well-being (Lazrus 2016; Sharma and Shrestha 2016). In these situations, individuals migrate to alternative sources of water according to their necessities and its availability, as for example in water tanks and waterholes. These actions are similar to the responses reported for sub-Saharan Africa and the Andes, where

Table 2 Results of the PERMANOVA and post-hoc tests to evaluate differences between the water sources used by the communities around the researched reservoirs

Source	DF	MS	*F*	P-perm	Permutations
Water sources					
Community	4	3.5327	3.7669	0.0001	9915
Residual	122	0.93785			
Total	126				
Post-hoc tests					
Community	*t*	P-perm			
Poções × Sumé	1.3803	0.1462			
Poções × Traíras	2.0826	0.0032			
Poções × Sabugí	1.7699	0.0001			
Traíras × Sumé	1.5314	0.052			
Traíras × Sabugí	2.9708	0.0001			
Sabugí × Sumé	1.4113	0.0874			

Table 3 Results of Pearson correlation for the relationship between water sources, transport form, and water use in the communities around the researched reservoirs

Average volume of water	Reservoirs themselves	Other smaller reservoirs	Rainwater	Well water	Waterholes (*Cacimba*)	Water tanks (*Barreiro*)	Commercial bottled water
	$r = 0.74$, $p = 0.08$	$r = -0.75$, $p = 0.08$	$r = 0.37$, $p = 0.004$	$r = 0.54$, $p = 0.02$	$r = -0.32$, $p = 0.01$	$r = -0.32$, $p = 0.01$	$r = -0.04$, $p = 0.07$
	Water distribution per resident associations	Mechanical pumping	Animal transport	Human transport	Tank trucks	Car	Motorcycle
	$r = -0.58$, $p = 0.03$	$r = 0.75$, $p = 0.08$	$r = -0.78$, $p = 0.09$	$r = -0.047$, $p = 0.01$	$r = -0.01$, $p = 0.08$	$r = 0.32$, $p = 0.01$	$r = -0.32$, $p = 0.01$
	Drinking	Cooking	Personal hygiene	Other domestic uses	Maintaining animals	Agricultural	Fishing
	$r = 0.88$, $p = 0.18$	$r = 0.56$, $p = 0.03$	$r = -0.55$, $p = 0.03$	$r = -0.40$, $p = 0.0007$	$r = -0.66$, $p = 0.05$	$r = -0.72$, $p = 0.07$	$r = -0.95$, $p = 0.35$

systems for irrigation and wells for domestic use are common, with small dams being built to furnish water for cattle (Butterworth et al. 2010).

The reductions in the water volumes of the major reservoirs can also explain the differences between the strategies used by the surrounding communities for water transport. In communities near reservoirs with small water volumes (Poções and Traíras), the residents tend to obtain water under drought conditions from sources quite distant from their homes, depending more on motor vehicles for its transport, as for example by tank trucks (principally), cars, and motorcycles. In communities near reservoirs that still hold considerable volumes of water (Sumé and Sabugí), more than 50% of that water is pumped through pipes to their residences. When those reservoir water volumes become even more reduced, the long distances between the residences and secondary reservoirs increase the costs of installing pipes and pumping the water. As such, the use of motor vehicles allows the transport of larger quantities of water that can be used over longer periods of time.

It is important to note, however, that even being able to adapt to a certain degree of stress caused by extended droughts, vulnerable populations demonstrate lesser capacities to mitigate the problems generated by that stress (Palta et al. 2016), becoming totally dependent on government programs to have access to water. In the study area described here, the families were dependent on tank trucks supplied by federal government programs (“*Operação Carro-pipa*”) run by the Brazilian Army (Campos 2015).

With decreasing water volumes in the larger reservoirs, there is a concomitant reduction in water quality caused by increasing concentrations of nutrients in the remaining water and blooms of green algae (Eskinazi-Sant’Anna et al. 2007; Santos and Eskinazi-Sant’Anna

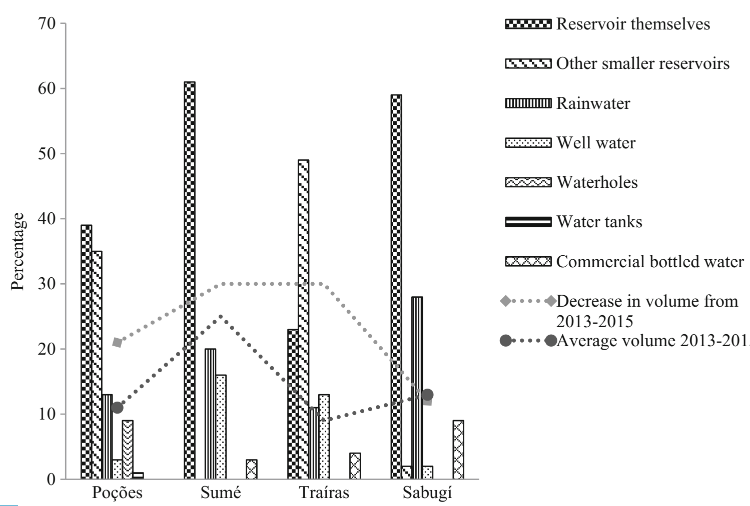

Fig. 10 Relation of the average water volume and reduction of the volume of the reservoirs with the sources of water used by the communities living in the vicinity of the researched reservoirs

Fig. 11 Strategies for transporting water: mechanical pumping (*1*), water truck (*2*), water distribution systems of the residents' association (*3* and *4*), water tanks for collecting water in the cisterns (*5*), and search by means of animal transport (*6*)

2010; Barbosa et al. 2012)—conditions empirically perceived by most of the interviewees, and which stimulated them to seek other sources of fresh water for drinking and cooking purposes. The water in those failing reservoirs is therefore principally used for bathing, general domestic needs (such as washing dishes and clothing), and animal use. Similar results were reported by Lazrus (2016) during interviews with individuals from a dryland community in Oklahoma (USA), who indicated that the primary use of any available water is for human drinking and cooking—although those uses are discontinued when water quality deteriorates because of extended droughts. Studies undertaken by Strauch and Almedom (2011) in the semiarid region of Tanzania likewise corroborated our observations, demonstrating that there are differences in river water uses during different seasons of the year (Dankers et al. 2014; Schewe et al. 2014), reflecting the importance of the climate in

Table 4 Strategies used by the residents of the researched reservoirs for water transportation. Ncit. = number of citations of interviewees, * indicate the absence of citation

	Water distribution per resident associations	Mechanical pumping	Animal transport	Human transport	Tank trucks	Car	Motorcycle
Poções	*	29% (Ncit. = 18)	21% (Ncit. = 13)	8%, (Ncit. = 5)	30% (Ncit. = 19)	6% (Ncit. = 04)	6% (Ncit. = 04)
Sumé	*	56% (Ncit =14)	4% (Ncit. = 1)	*	36% (Ncit. = 9)	4% (Ncit. = 01)	*
Traíras	31% (Ncit. = 16)	12% (Ncit. = 6)	12% (Ncit. = 6)	2% (Ncit. = 01)	43% (Ncit. = 22)	*	*
Sabugí	8% (Ncit. = 04)	53% (Ncit. = 25)	13% (Ncit. = 06)	*	26% (Ncit. = 12)	*	*

Table 5 Result of the PERMANOVA and Post-hoc tests analysis to evaluate differences between the water transport strategies among the researched communities

Source	DF	MS	*F*	P-perm	Permutations
Water transport strategies					
Community	4	4.8752	5.7176	0.0001	9907
Residual	122	0.852678682			
Total	126				
Post-hoc tests					
Community	*t*	P-perm			
Poções × Sumé	1.823	0.008			
Poções × Traíras	2.818	0.0001			
Poções × Sabugí	1.8427	0.0111			
Traíras × Sumé	2.4225	0.0004			
Traíras × Sabugí	3.5191	0.0001			
Sabugí × Sumé	0.9940	0.3943			

determining the availability and quality of the water resources held in reservoirs (Biemans et al. 2011) and other aquatic ecosystems—requiring alterations in water resource use patterns by those human populations.

The results reported here in relation to the treatment of water resources by local populations in the semiarid region of Brazil can diverge from other localities. Barros et al. (2013) reported that approximately 80% of the local population in the semiarid region of Paraíba State, Brazil, treated their water, although Fonseca et al. (2014) reported that 64% of the interviewees in the semiarid region of Minas Gerais State in the same country did not treat the water they consumed, similar to our findings. In terms of the methods used for treating water, our results were in agreement with previous publications (Barros et al. 2013) that indicated that the preferred method for treating raw water in the semiarid region of Brazil is by chlorination. The widespread use of untreated water is alarming, however, as numerous illnesses can be traced to polluted water, such as intestinal parasites (Prüss et al. 2002; Brasil et al. 2016) and protozoans (Fonseca et al. 2014).

Our results are an important source of data that can be used in the development of management and conservation plans for reservoirs in the semiarid region of Brazil. We advocate implementing participatory management and conservation plans because they involve local communities, stakeholders, and responsible government institutions, and are more likely to achieve sustainable management. Franzén et al. (2015) draws attention to four key factors that should be considered in order to allow the participatory

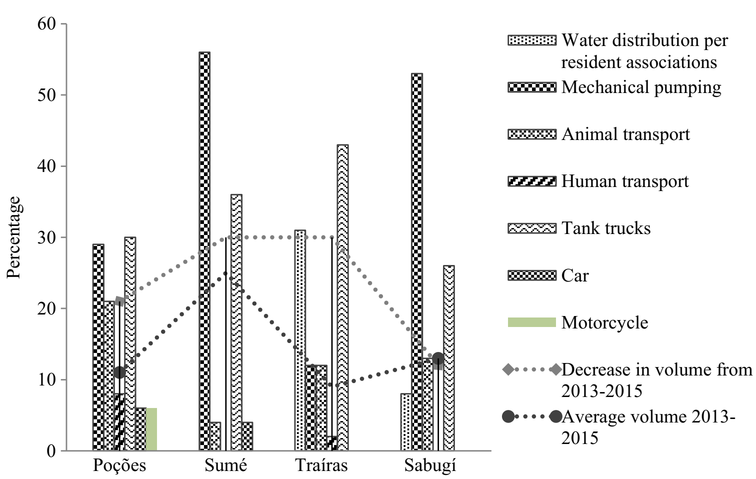

Fig. 12 Relation of the water volume of the reservoirs with the water transport strategies used by the communities living in the surroundings of the researched reservoirs

Table 6 Uses of the water of the reservoirs in which the residents live in the surroundings. Ncit. = number of citations given by respondents, * indicate the absence of citation

	Drinking	Cooking	Personal hygiene	Domestic uses	Maintaining animals	Agricultural	Fishing
Poções	6% (Ncit. = 10)	1% (Ncit. = 2)	21% (Ncit. = 33)	22% (Ncit. = 35)	22% (Ncit. = 35)	21% (Ncit. = 33)	7% (Ncit. = 12)
Sumé	15% (Ncit =17)	16% (Ncit. = 18)	18% (Ncit. = 19)	19% (Ncit. = 20)	16% (Ncit. = 18)	16% (Ncit = 18)	*
Traíras	3% (Ncit. = 4)	13% (Ncit. = 20)	19% (Ncit. = 30)	19% (Ncit. = 30)	18% (Ncit. = 28)	18% (Ncit. = 28)	10% (Ncit. = 15)
Sabugí	1% (Ncit. = 02)	9% (Ncit. = 14)	22% (Ncit =33)	22% (Ncit. = 33)	21%, (Ncit. = 32)	20%, (Ncit. = 30)	5%, (Ncit. = 8)

management of water resources: (1) existence of an organization involving key stakeholders committed to the scope and objectives; (2) institutional arrangements that are flexible and aware of the need to integrate stakeholders; (3) clear leadership to drive the achievement of the objectives and to evaluate the results achieved; and (4) voluntary involvement of local residents to participate in the implementation of measures and contribute knowledge and experience on local conditions. In the global scenario, two forms of participatory management, top-down and bottom-up, have stood out. Jacobs et al. (2016) analyzing these systems show that there is no definition of which model to adopt, the choice and success of the model depends mainly on the local reality, the commitment and feasibility of the activities outlined, yet forms of bottom-up management appear to have failed in long-term implementations.

In this context, management plans in this region should consider the characteristics of water level fluctuation and the ecological characteristics of local ecosystems, as well as the needs of human populations, knowing their sources, management and use of water, conditions and contexts of social and cultural aspects of life in the semiarid region (Alves et al. 2012; Gain et al. 2012; Grafton et al. 2013; Wolverton 2013; Schewe et al. 2014; Eufracio-Torres et al. 2016). Adaptations to climate change will require not only the improvement of local strategies, but also the creation or adaptation of institutional organizations so that they can organize and coordinate actions and interactions between individuals and their communities (Warner 1997; Scheffran et al. 2012; Koontz and Newig 2014; Xu et al. 2014). Those involved must understand that

Table 7 Result of the PERMANOVA and post-hoc tests to evaluate differences between water purposes among the communities around the researched reservoirs

Source	DF	MS	*F*	P-perm	Permutations
Reservoir water uses by local community					
Community	4	7.7358	9.3274	0.0001	9911
Residual	122	0.82936			
Total	126				
Post-hoc tests					
Community	*t*	P-perm			
Poções × Sumé	3.9453	0.0001			
Poções × Traíras	1.8193	0.0057			
Poções × Sabugí	3.1066	0.0001			
Traíras × Sumé	3.4407	0.0001			
Traíras × Sabugí	2.1549	0.0015			
Sabugí × Sumé	3.5107	0.0001			

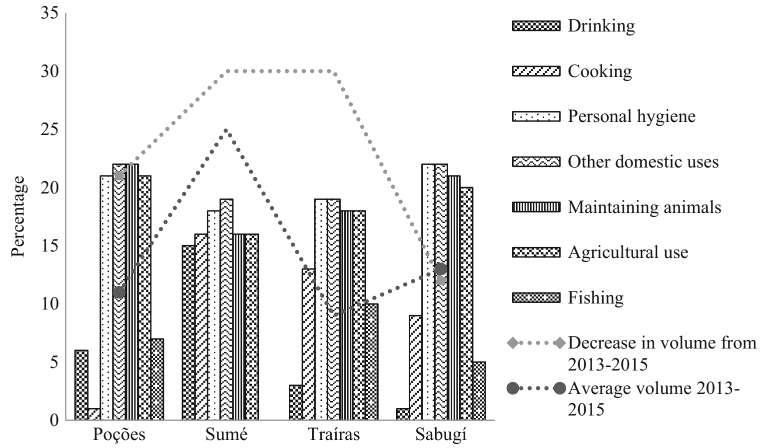

Fig. 13 Relation of the water volume of the reservoirs with the water uses by the communities living in the surroundings of the researched reservoirs

problem of drought in the Northeast of Brazil is not simply metrological—but also organizational, political, and social, so they must draw up management and conservation plans that ignore national emergency policy, should seek to cure the causes of water problems (Campos 2015). These changes in the management system will result in social and political transformations that will promote the more efficient use of available water (Butterworth et al. 2010; Florke et al. 2013).

An alternative that can be implemented in management plans in the region is the enhancement of rainwater harvesting during the rainy season, this measure could reduce water shortages during prolonged periods of drought (Lema and Majule 2009; Menezes et al. 2013). Technologies to that end have become well established in many arid and semiarid regions of the world (Gnadlinger 2011; Menezes et al. 2013). A program of the Brazilian federal government known as “A Million Cisterns—P1MC” has already been established in the semiarid region of that country and 582,816 cisterns have been constructed up until March 2016 (Articulation Brazilian Semiarid 2016). As such, the construction of large cisterns represents a viable manner to providing convenient water resources for human populations inhabiting semiarid areas for longer periods of time (Barros et al. 2013). One factor that favors the construction of cisterns is the high acceptance of these reservoirs by local residents. Studies undertaken by Menezes et al. (2013) in the semiarid region of Bahia State (Brazil) demonstrated that 41% of the interviewees used cistern water for cooking, 32% used it for drinking, 12% for personal hygiene, 5% for irrigation, and 5% as drinking water for animals.

Conclusion

Considering all of the factors analyzed in the present work, we have shown that prolonged drought situations exercise strong influences on human communities living near artificial reservoirs in the semiarid *Caatinga* region of northeastern Brazil. The inhabitants there have adapted to the use of alternative sources of water resources, varied forms of its transport to their residences, and different types of uses of water depending on its source and quality—demonstrating the continued vulnerability of humans and aquatic ecosystems that are exposed to climate change. It is important to note that water treatment in those areas is still quite precarious, which is reflected in public health statistics. It will be necessary to develop strategies, principally governmental, to better manage and develop scarce water resources as well as to integrate local populations into functional programs of water management. The implementation of participatory management plans is an alternative for the water problem to be attenuated. Different stakeholders should dialogue and define the best model to be adopted for the local context, whether top-down or bottom-up. The current reality shows us the urgent need to make effective decisions regarding the management and conservation of aquatic ecosystems, whether artificial or not.

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