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ABSTRACT: This paper analyses the central role of water infrastructure in the transformation of hydrosocial territories through a case study in the Forquilha catchment in Brazil's *Nordeste*. Decentralised state-led infrastructural development reinforced the resilience of communities to drought, leading to more sustainable water access by many families; this was further magnified through individual and collective initiatives. However, this entailed the overdevelopment of small-scale hydraulic infrastructure and the formation of small community-based hydrosocial territories, which changed water flows and social relations at different scales. We show how this has led to the loss of hydraulic connectivity and the fragmentation of the catchment and how it has weakened collective action vis-à-vis the state. The state staged a remarkable interventionist comeback in the catchment by connecting medium-sized reservoirs in the upstream part of the catchment to urban water supply networks. In the absence of negotiated water reallocation, this may lead to the loss of water and livelihoods by vulnerable groups.

KEYWORDS: Fragmentation, dispossession, resilience, hydrosocial territories, Nordeste, Brazil

INTRODUCTION

Water storage has been an important feature of Brazil's policies for dealing with drought in its semi-arid northwest (*Nordeste*). For almost a century, beginning in 1885, the main focus was on creating large-scale 'strategic' reservoirs (the so-called 'hydraulic solution'), in parallel with the development of irrigation schemes (Campos, 2015). After a "reflexive phase" in the 1980s (ibid: 1058), from the early 1990s on a decentralised water policy was implemented, with small-scale water infrastructure (reservoirs, cisterns) created at the community and household level to promote the paradigm of 'living with drought' (*convivência com a seca*; Lima et al., 2011). The main idea was to seek the active involvement of rural populations in the development and management of this infrastructure and to

reinforce the resilience of rural communities (Mattos et al., 2022). As a result, several government infrastructure projects were implemented to improve adaptation to drought and to build the long-term resilience of communities (Martins et al., 2016).

When we started this study in the Forquilha catchment (in the state of Ceará) in 2019, we observed a marked contrast between the state's perception of critical water shortages and that of peasant families we met in the catchment; the latter expressed their relief at the wetter year that had followed the prolonged drought of 2012 to 2018. The major 'strategic' reservoirs were, however, only filled to 4% of their capacity, thus threatening the supply of water to the cities and rural communities that had no other access to water (Burte et al., 2020). At the same time, there were now about 300 small reservoirs (*pequenos açudes*) in the catchment that had started to fill up, that is, more than one reservoir per km^2 (FUNCEME, 2021); peasant families were thus quite satisfied with water supplies. A *pequeno açude* is a small hillside reservoir that is created by constructing a simple embankment, or small earthen dam, that blocks a watercourse.

More generally, in the state of Ceará there has been a massive investment by state and local actors in small-scale water infrastructure (cisterns, reservoirs and boreholes), in particular through the well-documented São José projects that advocate the *convivência* paradigm (Carrick-Hagenbarth, 2018). There are now, in 2023, more than 105,000 *açudes* in Ceará, among which only 166 are monitored by the state (FUNCEME, 2021); there are also 36,947 boreholes (CPRM, 2023). In tandem with greater water use, this infrastructure has harvested increasingly large water flows and, more widely, has led to the spatial redistribution of water from downstream reservoirs to upper basins (de Araújo and Medeiros, 2013). The literature on the fragmentation of river systems focuses mainly on the adverse ecological impacts of the construction of large reservoirs (see, for example, Grill et al., 2014); in Ceará, however, while empty large-scale reservoirs may be the cause of river fragmentation in the downstream stretches of large rivers, these reservoirs are also affected by the development of small-scale water infrastructure in their catchment area (ibid).

Faced with empty strategic reservoirs during periods of drought, the government of Ceará state decided to construct large-scale water infrastructure to transfer water from river basins to the Fortaleza metropolitan area. Meanwhile, smaller cities in the interior also faced increasing problems with water supply. During the recent drought, for example, the city of Quixeramobim, the municipality to which the Forquilha catchment belongs, faced 11 successive months of water service failures (Barbosa, 2018). This explains the focus of municipalities on gaining access to upstream reservoirs in small catchments in order to capture water for cities and rural communities facing water shortages. This policy has created conflicts with other water users in the catchment around water sharing (Formiga Johnson and Kemper, 2007).

The proliferation of water storage facilities, along with the fragmentation of river systems and the spatial redistribution of water, challenge the conclusions drawn in the emerging global discourse on "a new water storage paradigm" for "more resilient water services" in the face of climate hazards (Burke et al., 2023: ix, x). These conclusions assume that constructing more water storage facilities and reducing the 'storage gap' of freshwater in the world will lead to higher levels of climate resilience (ibid: ix; Pangestu, 2023). In many water basins around the world, however, there is increasing evidence that 'over-development' of water infrastructure (Hennig and Harlan, 2018) – including of water storage facilities – often leads to the reallocation of water in environments where all water resources are already allocated and in use (Molle et al., 2010).

There has been much attention to, "the ways in which infrastructures simultaneously shape and are shaped by social and political forces" (Obertreis et al., 2016). This "relational understanding of infrastructure" (ibid) calls attention not only to how politics are, "embedded in and enacted through infrastructure", but also points to, "the various ways in which territorial relations are reconfigured through infrastructure" (Hommes et al., 2022). In hydrosocial territories, infrastructures and territorial relations are constantly (co)evolving through messy and contested processes (Obertreis et al., 2016).

Although they are often seen as stable and durable (ibid), a rich literature points to the multiple ways in which, "infrastructures are interpreted, understood, adapted, and integrated by its users in very diverse ways that often do not correspond with the original ideas of those that implement them" (Mirhanoğlu et al., 2023; see also van der Kooij et al., 2015).

In this study, using the lens of hydrosocial territories, we show the central role of water infrastructure in transforming hydrosocial territories through a case study of the Forquilha catchment, where a variety of water storage infrastructure has been implemented by the state, NGOs, local communities, and households. We first zoom in on one of the communities to understand how state- and NGO-led programmes of small-scale water supply infrastructure, alongside private individual and collective initiatives, have woven a dense web of water stocks, pipes and taps that are shaped by, but also reshape, social structures and networks. We then analyse, at the watershed level, how this (over)development and use of small-scale infrastructure disrupted water flows and the hydraulic connectivity in the watershed, fragmented the hydrosocial territories, and weakened social linkages around water while contributing to creating water shortages downstream. Finally, we examine how these hydrosocial territories are likely to be reshuffled by the transfer of water by the state from upstream reservoirs to neighbouring catchments.

ANALYTICAL LENS AND METHODS

Analytical lens: Investigating the central role of water infrastructure in transforming hydrosocial territories

In this study, we adopt a relational understanding of infrastructure that builds on the recent literature on hydrosocial territories (Obertreis et al., 2016). Hydrosocial territories are defined as, "socially, naturally and politically constituted spaces that are (re)created through the interactions amongst human practices, water flows, hydraulic technologies, biophysical elements, socio-economic structures and cultural-political institutions" (Boelens et al., 2016: 1). We concentrated on the relational networks around infrastructure within the hydrosocial territories and with outside actors (Neumann, 2009). Following Hommes et al. (2022), we identified how the water infrastructure in the Forquilha catchment came into being, the normative contents embedded in this infrastructure (in our case typically the community focus of the infrastructure), and the becoming of the infrastructure once it has been implemented. In our case study, we focused on the temporal and spatial dynamics of the hydrosocial system under consideration in order to visualise how the construction and adaptations of infrastructure shape and transforms territorial relations (Hoogendam, 2019).

In the literature related to the 'living with drought' paradigm in the Nordeste, the main analytical focus is on communities and households as these are the scales that are targeted by water infrastructure investments to mitigate drought (Carrick-Hagenbarth, 2018). Mapping and analysing the networks around infrastructure and paying attention to how hydrosocial territories are shaped by this infrastructure expands this focus in multiple ways (Hommes et al., 2022). First, Whaley and Cleaver (2017), in their analysis of water point functionality, saw the organisation of rural water supplies as "unnecessarily circumscribed" to (formal) community organisations, and thus encouraged to scrutinise the wider systems of governance. The community-driven development approach of rural water supplies indeed places the responsibility for sustaining these supplies on the community and away from the state. But, as Collard (2013) has shown, despite this community focus, communities and individuals in the Nordeste maintain strong links with state representatives, politicians and NGOs when dealing with problems in water infrastructure.

Second, Whaley and Cleaver (2017) observed that the focus of infrastructure programmes on "regularised and formalised" organisations and activities conceals the more informal arrangements around water. Community-level infrastructure projects in Brazil's Nordeste, for example, are typically

conducted with community associations that are legally recognised organisations that have a bank account and are mandated to engage in small-scale development projects. Indeed, community associations, "were often formed around a particular need rather than a geographic focus" (Carrick-Hagenbarth, 2016: 14); however, "the family, the hamlet (*sítio*), the community (*comunidade*), the networks of proximity" continue to play an important role in the rural areas (Caron and Sabourin, 2001). These informal forms of organisation are based on kinship, proximity, or shared experience. They are often governed by peasant reciprocity relationships that enable access to collective resources including water, land, and farm equipment (Sabourin, 2007). In the Nordeste, a typical rural community has from 30 to over 250 households which are often dispersed in several "nucleated settlements" (Ferreira et al., 2006). We define a nucleated settlement (NS) here as a group of households composed of neighbours and extended family who share water for drinking or other purposes on a daily basis and/or in times of stress.

Our relational take on infrastructure encouraged us to identify and analyse the "unique system of dynamic interactions and dependencies" within the Forquilha catchment. Our study considered both formal and informal organisations and networks and the multiple actors in the outside world (Honegger-Rivière and Ghiotti, 2022). This involved recognising the multiplicity and imbrication of scales, actors and infrastructure (Hoogesteger et al., 2016). We show the complexity of defining territories in space because a hydrosocial territory can correspond to, or limit, a watershed or can extend beyond it. In our case, the hydrosocial territory was not closed; on the contrary, it was in direct communication with outside actors, such as the neighbouring cities (through water tankers and pipelines), representatives from local or state administrations, politicians and NGOs. Moreover, we extended the analysis beyond the habitual formal community association and households by showing the important role of more informal arrangements, particularly at the level of nucleated settlements.

Study area and data collection

Study area

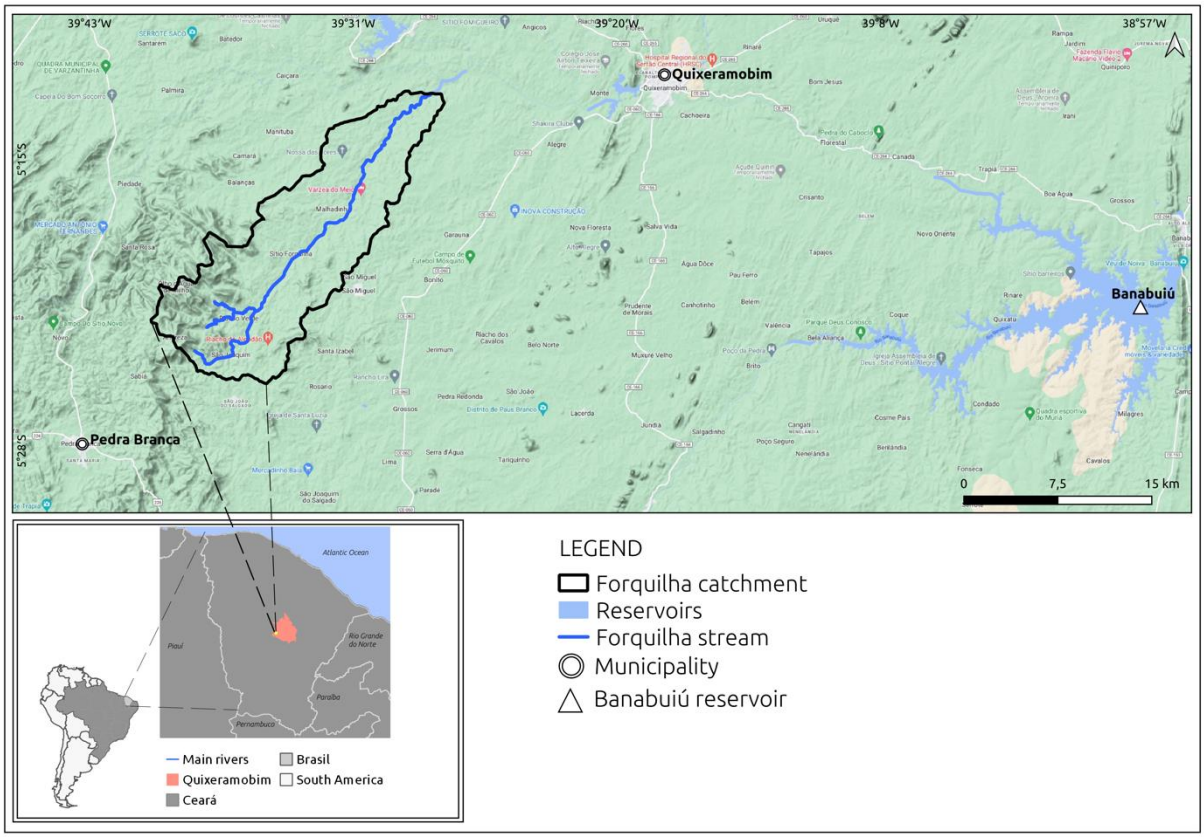
The 221 km^2 Forquilha catchment in the Quixeramobim municipality (Ceará state, Northeast Brazil; Figure 1) is part of the Banabuiú Basin. This basin includes the strategic reservoir Banabuiú (1.6 Bm^3 capacity), one of the three biggest strategic reservoirs in Ceará. The population of Quixeramobim municipality is distributed between a diffuse habitat and an urban core. In 2022, the population was 78,500 inhabitants, 39% of whom lived in rural areas according to municipal data. The population of the Forquilha catchment is divided into 17 communities, each with its own community association.

Agriculture in the Forquilha catchment consists of cattle ranches, subsistence family farming of maize and beans, and small-scale animal husbandry. Irrigated horticulture and fruit farming are practised downstream in the catchment. The climate is semi-arid and rainfall is extremely irregular in terms of frequency and intensity. The average annual rainfall in the period from 1988 to 2022 was 657 mm (FUNCEME, 2022). The climate is characterised by two seasons: a rainy season from February to April and a dry season from May to January.

There are three sources of water for domestic and agricultural use: surface water reservoirs (*açudes*), small alluvial aquifers, and cisterns that are filled either with rooftop rainwater collection by households or by water tankers sent by the state. Indeed, the main strategy of rural communities and development organisations is the creation of different types of water infrastructure with diverse water sources (Gasmi et al., 2022). This includes: 1) individual and collective cisterns with a volume of 16 m^3 for drinking and/or domestic uses; 2) community water supply systems that take water from the alluvial aquifer or from small or medium-sized reservoirs; 3) drilled boreholes (60 m deep) in crystalline areas; and 4) constructed alluvial wells (2-15 m deep) (Pinheiro and Fabre, 2004). The alluvial aquifer extends over 6.0 km² (23 km long and 250 m wide) with an average sediment depth of 6.8 m and a piezometric level of 2.8 m below ground level at the end of the rainy season (Burte et al., 2005). Five medium-sized public reservoirs are

located in the upper catchment, while the groundwater in the lower catchment is mainly used for irrigation, watering cattle, and domestic purposes (Burte et al., 2009). These infrastructures generally cater to different water uses, including drinking and domestic water and use for agriculture and livestock.

Figure 1. Location of the Forquilha catchment connected to Rio Quixeramobim, which feeds the large-scale Banabuiú reservoir, Ceará, Brazil.



Each community water supply system includes a collective network with an electric pumping system that takes water from a community açude, well, or borehole, as well as a water tower and a piped network that supplies the households. The management of the water source (açude, well, borehole) is often the responsibility of the community association.

Data collection

Data collection for this study involved a mixed methods approach at several scales. Qualitative and quantitative data on rural water supplies in the Forquilha catchment were collected between 2019 and 2023. We first collected data about the policies and projects that had been implemented to enhance rural water supplies in Ceará; this data collection was based on a review of working papers, organisational websites and official documents.

Second, the research for this paper was facilitated by a recent inventory of the rural water supply infrastructure in the Forquilha catchment (FUNCEME, 2021). There are different types of infrastructure (wells, tube wells, reservoirs, cisterns, community water supply networks), that depend on different water sources (surface water, groundwater, rainwater, water tanker) and are managed by various actors (mainly communities, or individual or multiple households in a nucleated settlement). We mapped the connections among community members and outside actors with regard to specific infrastructure in

order to identify the rules governing the use of that infrastructure and to trace its historical evolution (design, implementation, maintenance and use).

We conducted 30 surveys and 24 interviews with community members and leaders and with leaders of community associations. We analysed stakeholder discourse through investigations, participatory mapping (Figure 2), and life stories. To do so, we used hydrosocial narratives (Bell, 2002; Leong, 2021) to capture the complexity of past changes in hydrosocial territories in the Forquilha catchment. The actors we met had long-standing experience in dealing with the consequences of drought; they had a dynamic view of infrastructure and of the rules governing water supply systems, and understood that they needed to be continuously adapted by mobilising relational networks (Jones and Tanner, 2017).

Figure 2. Participatory mapping of hydrosocial territories in Forquilha catchment with community members (left); identifying the nucleated settlements of Varzea do Meio community (right).

Source: Left: Marcel Kuper (2023); right, Letícia Vieira (2023).

Third, 20 semi-structured interviews were conducted with state and regional stakeholders (state officials, policymakers and NGO staff) in order to understand how water infrastructure projects were implemented. This was complemented by observations of, and interviews with, members of communities, truck drivers, construction workers, and staff of the state water company.

Fourth, we conducted a detailed investigation of the Varzea do Meio community, one of the 17 communities in the catchment. This community (19 km^2) is composed of 90 families and has always been involved in collective action on water issues at the community and catchment levels. Thanks to an active community association, the community has good connections with external actors (Gasmi et al., 2022). We identified the different nucleated settlements and their inhabitants using participatory mapping and interviews, finally using drone footage to confirm their geographical limits.

Fifth, we held a series of six participatory workshops. Three workshops with community members (8 participants in each of the first 2 workshops and 15 participants in the third) were aimed at identifying adaptations made to water infrastructure and rules made by the community to cope with drought. A workshop was subsequently held with 20 stakeholders from national and regional water institutes, research institutes and NGOs to identify different visions of rural water supplies. This was followed by a mixed workshop with 29 stakeholders from national and regional water institutes, research institutes, NGOs and community members to validate the definition of rural water supply systems and to analyse

their trajectory. Finally, a territorial workshop was held with representatives of nine communities in the Forquilha catchment to identify the catchment's trajectory and its different hydrosocial territories.

RESULTS AND DISCUSSION

Weaving water and the social: The example of Varzea do Meio community

Varzea do Meio, one of the catchment's 17 communities, provides a good illustration of how water infrastructures and social structures are intermingled through a multitude of projects, investments and initiatives.

A wide range of water projects to build resilience

In the context of consecutive droughts, Ceará state has been promoting a 'living with drought' public policy to enhance the resilience[1] of rural communities (Milhorance et al., 2022). The community scale was identified as an appropriate level for state intervention (Collard, 2013). The World Bank, as part of its wider international discourse on community-driven management, supported the development of rural water supply projects at this scale (Coirolo et al., 2001). It was felt that community-scale infrastructure would help avoid misappropriation of money and would ensure more local participation in public actions (Masud et al., 2019). To benefit from state- or NGO-driven rural water supply projects (and more generally from development projects), rural communities needed to be organised into community associations.

The focus on rural water supply projects for rural communities led to a drive to ensure sustained water supplies through a single 'replicable', albeit 'locally tailored', rural water supply system. This should include, "small wells, rainwater collection, surface water collection by individual households (for example, carrying water in barrels from nearby ponds or small reservoirs or relying on water collected by tankers from distant reservoirs), and small reservoirs" (Enéas da Silva et al., 2013). Several studies have shown that rural communities in Brazil and elsewhere diversify water sources and multiply infrastructures in order to ensure sustained water supplies (Smits et al., 2010). In Ceará, the state and NGOs have long supplied a wide diversity of water infrastructures at the household level (individual cisterns) and at the community level (collective cisterns, community rural water supply systems); however, the resilience of rural communities to drought has also been enhanced by progressive public social policies (rural retirement pensions, family allocations) (Sabourin et al., 2022; Mattos et al., 2022).

The Forquilha catchment has benefited from multiple interventions by the state and NGOs, and individuals and collectives have been actively developing infrastructures. This was one of the factors that explained why our interviewees considered that the impacts of the 2012-2018 drought were less drastic than those of previous droughts. As one member of the Lagoa Cercada community told us in an interview, "I am afraid of one day returning to my father's time. My father used to drink a glass of water mixed with mud. There was no water in the 1980s. Today, there is water here, even if it is salty, there is water".

A 'nucleated settlement' is the basic unit of water solidarity

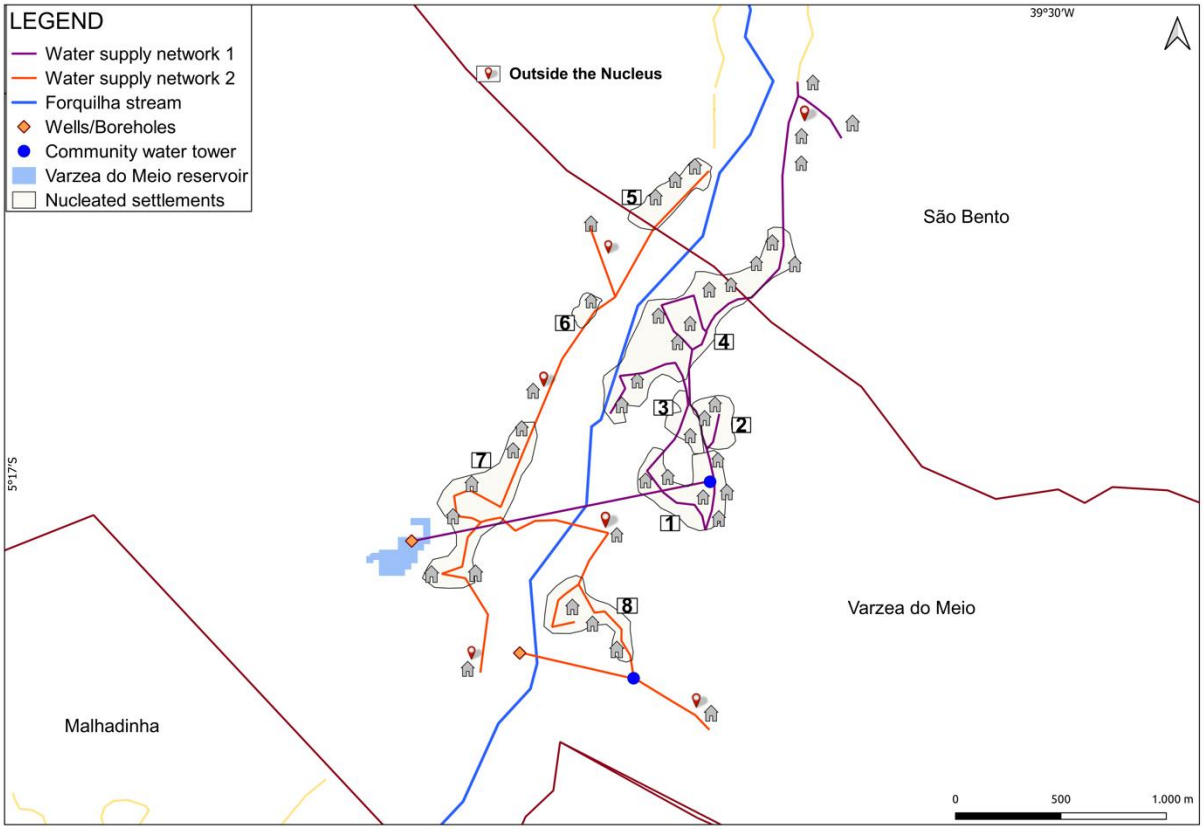
Our fieldwork and workshops with members of the Varzea do Meio community showed that the basic unit of water solidarity is the nucleated settlement (NS) as we have defined it above. Inhabitants of Varzea do Meio identified eight such settlements (numbered 1 to 8 in Figure 3), some of which straddled two communities. According to our interviewees, to belong to an NS one has to have a shared history of

[1] A rural community is considered resilient by Frankenberger et al. (2013: 1) when, "it can function and sustain critical systems under stress; adapt to changes in the physical, social, and economic environment; and be self-reliant if external resources are limited or cut off".

drought and to have collectively struggled to obtain water and productive infrastructure. Within these NSs, the informal arrangements to facilitate access to water are generally based on geographical proximity and personal affinity (kinship, neighbours) and on the principle of reciprocity. The arrangements for (shared) access to water are thus imbricated in, "multiple (family, business and labour) relations" (Gasmi et al., 2022). The support networks inside the nucleated settlements are not formally linked to the community association, although in practice there are many interactions. These networks also do not necessarily follow the limits of the community association. The five red dots in Figure 3 represent families who come from outside the catchment and do not belong to any NS.

We started our analysis with the two community water supply networks that have existed since 2017. The networks were planned for the delivery of drinking water, but the communities instead use the untreated water for a wide range of other uses around homesteads, including irrigation and watering livestock (Gasmi et al., 2022). The first water supply network supplies 60 houses that belong to NSs 1 to 4; it draws from a well belonging to a large landowner who lives in town and, from 2023 onwards, it has drawn water from a community reservoir. The second network supplies 30 houses belonging to NSs 5 to 8 from a private well belonging to a community resident, for which residents only pay the electricity cost.

Figure 3. Nucleated settlements and community water networks.



The social organisation of the Varzea do Meio community association is hierarchical, with NS1 at its centre; all other groups are both spatially and socially peripheral to it. NS1 participates actively in collective actions for the benefit of the community. It is composed of households belonging to two large families who are all cousins. Two brothers and a sister have been swapping the functions of president and treasurer of the community association among themselves and their influence has played a role in obtaining access to water sources (wells and a community reservoir) and agricultural aid from the state.

The social cohesion among the members of the family group is strong. They share private cisterns in times of need and they do so on a continuous basis with families who have no cistern: "My well never dried up, I use it for irrigation. I let people get water there for free, people can go there, I don't even charge for electricity. I leave it open so they can get in to get the water and that's it" (Interview with a member of NS1 in Varzea do Meio).

Members of NS1 lobbied for, and were then actively involved in organising, a community water supply system, a primary school, a community centre and a milk collection facility. Despite the strong social role of this group, they all agreed on the importance of interacting with other NSs to ensure a sustainable water supply. Members of this NS have developed a strong external network that includes the municipality, the mayor, and agricultural services. They stay informed about all calls for projects published by the state and by NGOs to solve individual or collective water problems.

Although NS2 and NS3 are geographically linked to NS1 (Figure 4), they only play a passive role in the community water association. Families receive domestic water from the community network but at the same time they share a small reservoir for agricultural use. They also have an alternative water network based on a private well to which several houses are connected. In case of water shortage, the members of these settlements help one another or look for outside help from a neighbouring settlement, the community association, or external actors. NS4 is made up of an extended family that is not integrated into the community. They are not satisfied with the operation of the community association, especially as the management is still in the hands of a single family. As a consequence, they receive no support or subsidies from the state through the association, which has created a feeling of exclusion for them. An agent of the extension services of Quixeramobim city lives in this settlement, however, which has facilitated their connection to external regional actors.

Figure 4. Photo showing Nucleated Settlements 1, 2 and 3.

Source: Drone photo by Letícia Vieira (2022).

NSs 5 to 8 receive water from the second community water supply network. Each settlement shares their drinking water cisterns with houses that do not have one. In NSs 5 to 7, thanks to their proximity to the river, some inhabitants have wells that provide water for their livestock or for irrigation. These three settlements were able to ensure their water supply even during the multi-year drought, however the water was only shared in critical periods. NS8 receives water from the same network. This settlement is located in the highest area of the community and is considered clandestine while its inhabitants are considered to be marginalised outsiders. Descended from slaves, the original members of NS8 found refuge in this small area of fertile land, which has since become highly fragmented due to inheritance. They help each other with water from their drinking water cistern but they are less connected to the other NSs and to external actors.

The analysis at the NS level revealed the wide range of water sources that operate at that level (collective and individual drinking water cisterns; collective and individual wells, boreholes and individual or small reservoirs for agricultural purposes and watering livestock). These settlements, however, are part of a community whose association played an important role in obtaining and operating the community rural water supply systems. Families' water access in times of drought is therefore linked to both the NS and to the community to which they belong.

The important role of community associations

While some families may have individual political contacts, obtaining and then managing community-based water development projects requires an active community association. As illustrated in the preceding section, the community association of Varzea do Meio obtained access to multiple sources of water through collective action and through their connections with the local elite, politicians and the state (Gasmi et al., 2022). Despite several droughts, the Varzea do Meio community has thus managed to maintain sustainable access to water.

In 2018, it negotiated with the Company for Water Resources Management of the State of Ceará (COGERH) for the construction of a community reservoir to recharge the alluvial aquifer, as the previous water source (a private well belonging to a large landowner) was considered too expensive (Figure 3). The negotiation with the state was at first informal via their political network, but it was subsequently formalised through the active community association. At the same time, the leading families (in NS1) negotiated with the inhabitants of NS7, which donated part of their land to build the community reservoir of Varzea do Meio. This alliance enabled the leading families to obtain an alternative and less expensive water source for the first network (NSs 1 to 4), while it gave the inhabitants of NS7 the advantage of using the reservoir directly to grow fodder crops in its vicinity.

After the community reservoir was completed, it took almost four years – till December 2022 – for it to be filled. In the meantime, the association had to continue renting the well from the large landowner. The water association ensured that users contributed to renting the well and paying for the electricity used to pump water for cattle and to irrigate fodder crops. But in 2022 the price of electricity increased significantly, coinciding with the accumulation of water in the community reservoir. The community contacted the Quixeramobim municipality and asked for help to connect the community water network to the small reservoir to increase their autonomy. This is a good example of how the community succeeded in activating connections with external actors.

Water supply is regulated by rules of use, which are defined locally. These rules and the price of water vary from one community to another and are defined collectively in association meetings. In these community networks, a sense of belonging was developed around the collective use of water infrastructures, uses, rules and organisational arrangements, but the different nucleated settlements also arranged for alternative water supplies thus avoiding complete dependence on the community association. Importantly, the community association also catered to water demand beyond the limit of the community, in this case from some households in the nearby community of São Bento.

The gradual fragmentation of the Forquilha catchment

The example of Varzea do Meio illustrates the active role of informal networks and community associations in ensuring durable access to water supplies, however communities also depend on water flows and sociopolitical dynamics at the catchment scale. Conversely, community-based water development projects influence water flows and sociopolitical dynamics at the catchment scale. Moreover, interventions from outside actors not only concern community-based projects, but also target catchment-level projects and households. To identify the water-related dynamic interactions between the communities of the Forquilha catchment and between communities and outside actors, we explored the historical, cultural and political settings of the catchment by co-identifying the current six hydrosocial territories (Figure 7). The criteria for this patterning were shared water resources, similar water practices, geographical proximity, past conflicts and a shared history of drought mitigation. The criteria were identified during our investigation in the Forquilha catchment (from surveys, interviews, life stories and participatory maps) and were then validated at a territorial workshop with representatives of communities.

A closer look at these territories reveals an impressive number and diversity of water infrastructures that have been developed through various initiatives (see Appendix 1). In addition to the collective water infrastructure implemented by outside actors at the catchment or community level, families have built 279 small reservoirs and have dug 108 individual wells and boreholes (Appendix 1). This explains the improved and robust water access perceived by the communities. As one community member described in an interview:

> The drought of the 1980s was cruel, we had to transport water by donkey. We went wherever there was water to drink, to cook or we dug a shallow well in the stream to get water. But in the last drought when it dried up here in 2015 the municipality helped us, water tankers came to fill our cisterns, they also installed a water tower for the community.

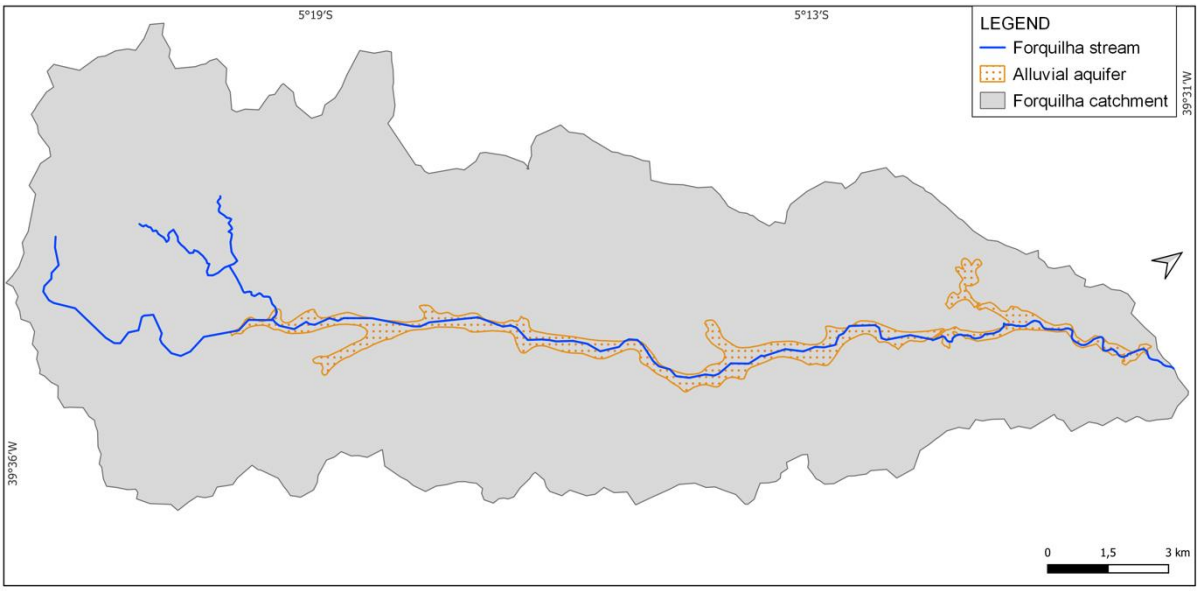
At the same time, the multiplication of water infrastructures explains the increased use of water for domestic purposes and (especially) agriculture, which disrupted the flow of water between the territories and fuelled a feeling of competition for water. As a member of Varzea do Meio community commented in an interview, "There are three big reservoirs upstream of Forquilha (town). The communities with water plant nothing there but do not release water to those who irrigate downstream of Forquilha town". Importantly, our interviews showed that communities feel much less connected to the upstream or downstream territories than they did in the 2000s as they now rely on water infrastructure at the level of communities and NSs. The massive introduction of water infrastructure in Forquilha catchment thus led to its fragmentation, resulting in the formation of smaller-scale hydrosocial territories. In other words, "These overlapping hydro-political projects tend to generate 'territorial pluralism' and make diverse 'territories-in-territory' – that is, overlapping, often contested, and interacting hydro-territorial configurations in one and the same space" (Boelens et al., 2016: 8).

The current pattern of hydrosocial territories in our case study is the result of a dynamic reconfiguration of available water resources, water infrastructure and water use arrangements in recent decades (Boelens et al., 2016). Workshop participants commented that the catchment had evolved from a single hydrosocial territory in 1970 to six hydrosocial territories in 2023. To explain this gradual fragmentation, we periodised changes in hydrosocial territories as follows: 1) a period of shallow dug wells (1970-1988); 2) a period of community water infrastructure development (1988-2010); and 3) a period of fragmentation of hydrosocial territories.

1970-1988: The period of cacimbas (shallow dug wells)

In the 1970s, there were no reservoirs in the catchment. According to the workshop participants, the catchment formed a single water territory, with the Forquilha River forming its structural axis (Figure 5; Burte, 2008).

Figure 5. A single hydrosocial territory in the Forquilha River catchment from 1970 to 1988.



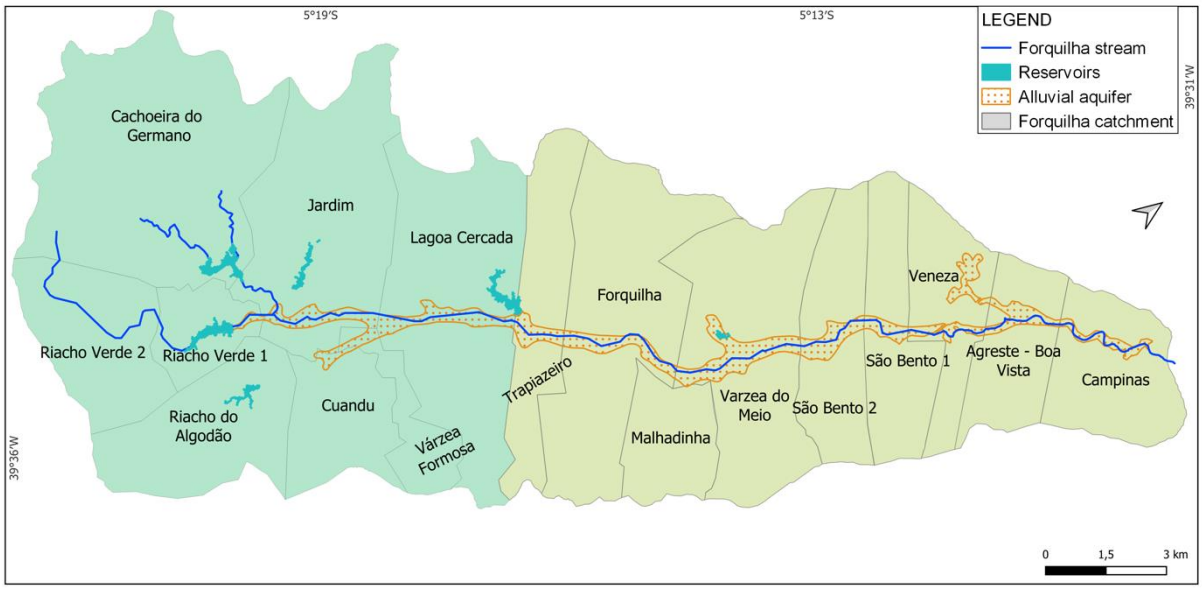
At the time, there were similar practices for obtaining access to what were considered shared water resources. In the rainy season, the communities only used surface water. In the dry season, the main water resource for domestic water was the alluvial aquifer, which was tapped through shallow dug wells or holes (*cacimbas*) and replenished during the rainy season. The dug wells were used during the dry season to water livestock and for domestic purposes. Due to the dispersed habitat, however, some households that were located six or more kilometres away from the river had problems accessing water, thus challenging the vision of a single homogeneous water territory. As an ex-president of a community association told us in a January 2023 interview, "We had a guaranteed water supply through these *cacimbas* but it was really difficult to fetch water and to regularly maintain them".

1988-2010: State-led water infrastructure development in the catchment – Convenience or dependency?

The construction of water infrastructure – reservoirs, wells, and especially the construction of four public reservoirs in the upper part of the catchment – modified the hydrosocial territory dividing it into two territories: an upstream territory containing reservoirs and a downstream territory that remained organised around the river (Figure 6; Burte, 2008).

Following droughts in the early 1980s, in 1988 the first collective public reservoir, with a capacity of 7 million m^3 (Mm^3), was built in Riacho Verde as part of public policies focused on coping with drought. The reservoir provided water to the Riacho Verde community for all uses. It progressively gained importance for fodder production and livestock rearing, thereby increasing water consumption (Appendix 1). In 2002, the state constructed three other reservoirs upstream, thus creating a territory of four reservoirs.

Figure 6. Two hydrosocial territories in the Forquilha catchment from 1988 to 2010.



In 1998, along with the introduction of wells, rural electrification became a key factor of change. As part of a water infrastructure project, a well was drilled almost every 100 m along the river, especially in the downstream sections (Burte, 2008). Wells were used to supply water for domestic, drinking and agricultural purposes. Water availability and a sense of abundance prompted inhabitants to practice intensive irrigated agriculture, especially horticulture and fruit farming. Increased water use through irrigation in turn lowered the water table, thereby jeopardising irrigated agriculture. During the drought year of 1998, the Quixeramobim municipality requested that water be released from Riacho Verde reservoir to sustain the Forquilha stream. Water was released without consulting the Riacho Verde community and the reservoir was emptied in a few weeks. This was the first instance of water 'dispossession' experienced by upstream communities. Angrily, members of the Riacho Verde community shut off the water supply and informed the municipality and other communities that they would never release water again.

Meanwhile, downstream communities continued to push for the release of water from the Riacho Verde reservoir for aquifer recharge. In 2003, meetings were held between local communities and institutional actors and an agreement was reached to release water, but in an organised manner. In 2004, the reservoir of Riacho Verde was refilled with rainwater making water release possible. By contributing collective labour (*mutirão*; Sattler et al., 2015), communities cleaned the river and dug ditches. Water was then released in a controlled way, with some water remaining in the açude for the local community. The water released, however, only reached halfway down the catchment. Moreover, many arguments arose during releases due to the conflicting interests of communities and the laboriousness of the riverbed cleaning. The drought of 2012 put an end to water releases from the upstream reservoir.

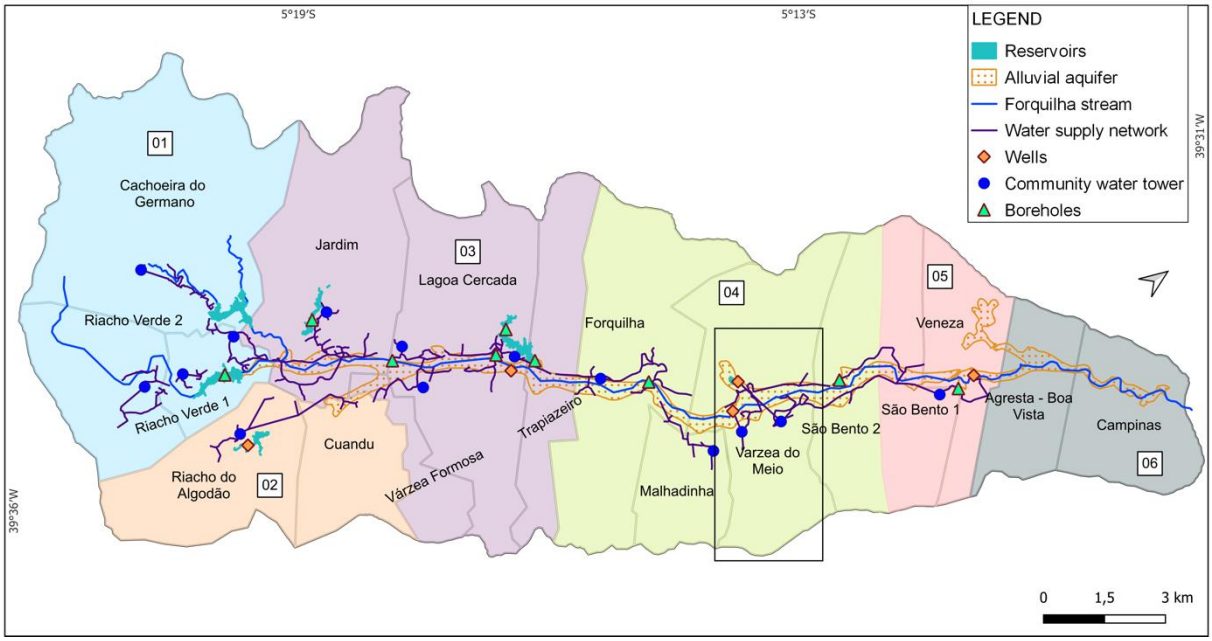
External actors such as the state and NGOs provided downstream communities with collective water cisterns, each cistern supplying 10 families. In the dry season, the cisterns were filled by water tankers and the water was reserved for drinking. Since 2000, government projects have supported the development of community water infrastructure including small reservoirs, collective distribution networks and drilled wells. These rural water supply systems gave a degree of autonomy to communities in accessing domestic water, thereby improving quality of life and reducing social tensions in the catchment. Providing water infrastructures without a sustainable local management model, however,

made communities highly dependent on the local economic agents and politicians who were able to guarantee that drinking water would be supplied by water tankers during droughts.

2010-2023: The gradual formation of six hydrosocial territories

In the past, interactions between families were shaped around the river and its individual and collective use (Neumann, 2009). Without interdependence around water, however, the Forquilha network has literally become 'dry', thus explaining its fragmentation into six hydrosocial territories (Figure 7). During the workshops in 2022/2023, several participants expressed their desire to reunite the communities and the catchment. As one workshop participant commented, "Bringing the catchment together to create projects would be great". This was mostly expressed by representatives of downstream communities, however, as upstream participants were cautious about restoring a collective dynamic in the catchment, presumably to avoid claims from downstream participants on upstream reservoirs. This points to the paradox that successful collective action at the level of nucleated settlements and communities – which in turn materialised in the six hydrosocial territories – could in the end lead to internal division at the scale of the Forquilha catchment.

Figure 7. The six hydrosocial territories in Forquilha catchment in 2023.



Note: The figure combines individual participatory maps that were validated during a workshop in Forquilha.

In 2010, all 17 communities of the Forquilha catchment submitted a joint application to the municipality for the construction of a reservoir in the upstream community of Cachoeira do Germano. This initiative demonstrated the collective force and the robust social network of the communities. Problems soon arose with the Cachoeira community, however, when they were confronted with the loss of arable land and the displacement of households. To facilitate social acceptance of the construction of the 4 Mm^3 reservoir, the state agents promised that all the communities would be able to use the water in the reservoir. The reservoir would thus enable the development of productive activities in the downstream part of the catchment while guaranteeing access to water for upstream communities. It would allow aquifer recharge for downstream communities and would ensure the supply of drinking water for the entire catchment through a piped network. These promises were never fulfilled, however, and only

Cachoeira and (some) Riacho Verde communities currently have direct access to the reservoir, while the state uses it to fill its water tankers, supplying water to households outside of the catchment.

The upstream catchment now includes four main reservoirs with multi-year storage capacity. Upstream communities in three separate hydrosocial territories have organised water uses around these reservoirs. In addition, many households have constructed small individual reservoirs (133 in the 3 territories), in particular for irrigated fodder production. The communities downstream have been deprived of water due to enhanced upstream storage capacity and reduced recharge of the water table. This spurred the fragmentation of the downstream catchment into three hydrosocial territories, where each community or group of neighbouring communities organised itself separately to respond to the new situation and enhance their own water security.

A number of consequences followed from the fragmentation of hydrosocial territories. First, the population had difficulty undertaking collective action to solve issues that reached beyond the community, as illustrated by the events around the Cachoeira reservoir. This applied not only in terms of negotiating solutions with the state (such as limiting water diversions), but also in terms of social mobilisation and contestation. State representatives and politicians have become privileged interlocutors of rural communities, who consequently spend less and less time discussing issues among themselves (Collard, 2013). Yet, collectives willing to shape their hydrosocial territory also need to solve water conflicts within their collectives and to defend their rights against the threats posed by powerful outsiders including state agencies (Hoogesteger et al., 2016). To this end, they need to cooperate and to mobilise their members to protect and control a common water resource (Hoogesteger and Verzijl, 2015).

Politicians project themselves as being an integral part of the history of the communities and as being committed to improving the situation in the catchment. Proximity to politicians thus ensures a certain level of security (for example, in the financing of community water infrastructure) and a feeling of being represented. At the same time, the emphasis in politicians' narratives on infrastructure projects as vectors of beneficial change and modernity makes it difficult for communities to develop alternative discourses (Figure 8).

Figure 8. Political event held in the catchment of Forquilha to announce a road construction project and a political commitment to constructing a pipeline to supply all communities of Forquilha using the Cachoeira reservoir.

Source: Photo by Julien Burte (2023).

Second, communities have consistently sought to diversify their sources of water for multiple uses and, at the same time, to maintain relations with different strategic outside actors (Gasmi et al., 2022). Some

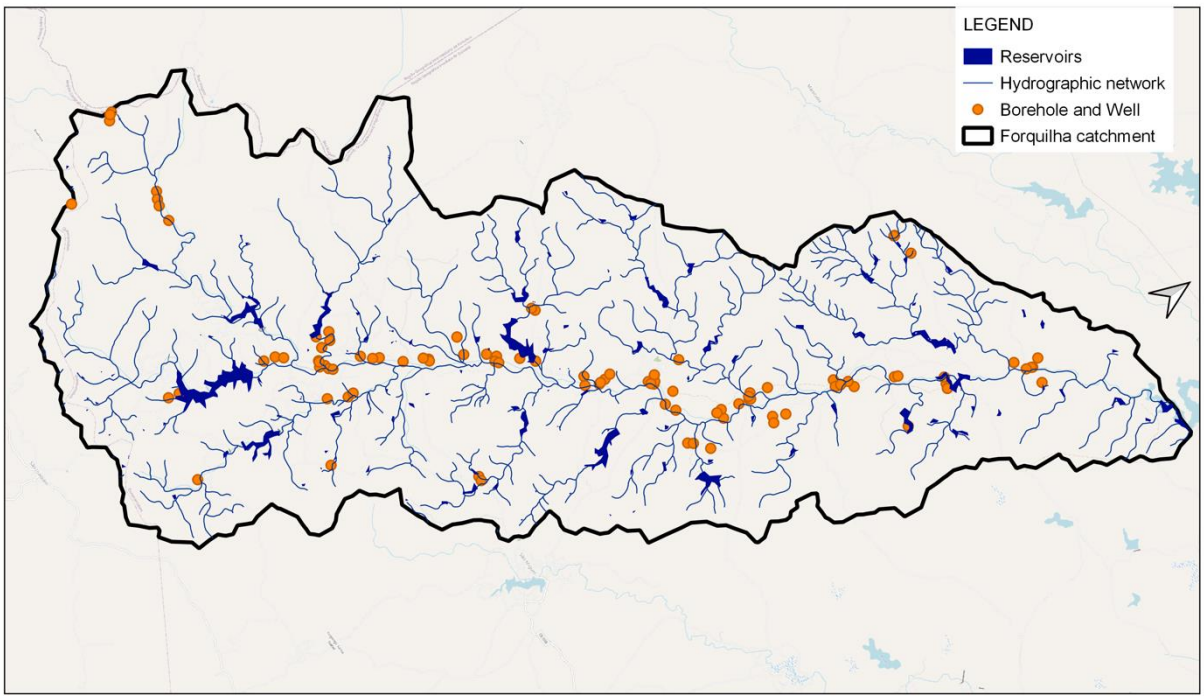
households and communities, however, have become increasingly dependent on a single source and a single actor – often a state service or politician – which increases their vulnerability. Akallah and Hård (2020), in two settlements in Kenya, similarly showed that communities that rely only on piped water were more vulnerable to water shortages than inhabitants who have several water sources. Increased convenience, therefore, does not automatically mean increased water resilience.

Third, not all communities have been able to successfully negotiate their dependence on the state, as we observed during our territorial workshop. As asked by the president of the Riacho Verde community association to the ex-president of the Varzea do Meio association during the January 2023 workshop, "How did you succeed in getting these water infrastructures? When we asked to rehabilitate our under-dimensioned network, the answer we got from the state was no, because there are situations worse than ours". In fact, some communities with a strong territorial integration have obtained support to cope with adverse conditions, while other communities have faced increased water stress.

Water transfer out of the Forquilha catchment: Reshaping hydrosocial territories

In 2017, the Banabuiú Basin, of which the Forquilha catchment is part, was in a critical situation due to the severe 2012-2018 drought, with nine strategic reservoirs dry and seven with water only in dead storage (Rabelo and Lima Neto, 2018). In 2019, when the rains returned, reservoir levels were barely restored, and in 2020 reservoir levels remained at 9.5% despite 912 mm of rain that year. This failure of reservoirs to refill can be explained by the massive amount of individual and collective water infrastructure in the different catchments, along with the increased use of water for agriculture and livestock; for example, almost 279 reservoirs and 108 boreholes and wells are currently in use in the Forquilha catchment (Figure 9). This has caused the spatial redistribution of water in the state of Ceará from large-scale downstream strategic reservoirs to small reservoirs upstream (de Araújo and Medeiros, 2013; Frischkorn et al., 2003; Malveira et al., 2007).

Figure 9. Map of the Forquilha catchment in 2021, with 279 reservoirs and 108 boreholes and wells.



Source: FUNCEME, 2021.

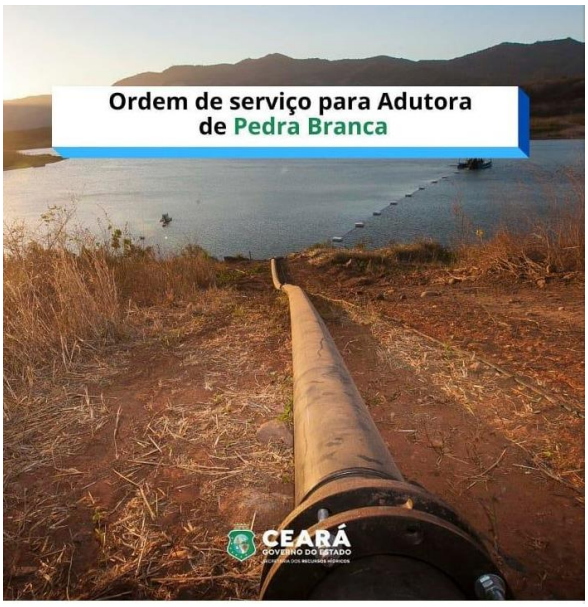
Note: Only five reservoirs are medium-sized public reservoirs, the rest are small private reservoirs.

Viewpoint of the communities: Rediscovery of watershed interdependence

The large reservoirs situated close to the study area (Pedra Branca, Fogareiro and Quixeramobim) have failed to supply sufficient drinking water to cities. This has motivated the state to consider transferring water from upper catchments to the city, which is considered to be a 'priority' user under National Water Law No. 9433 (Brazil, Ministry of Environment, Water Resources Secretariat, 1997). This led to the decision, after the drinking water crisis in 2022, to transfer water from the Cachoeira reservoir in Forquilha catchment to the nearby city of Pedra Branca. The reservoir at this point was already a strategic supply point for water tankers delivering water to rural communities outside of the Forquilha catchment.

COGERH, the state water resource company, failed to inform the communities of Forquilha about the decision to transfer water, even though the same water law specifies that, "Water resources management should be decentralized and rely on the participation of the government, users, and communities" (ibid). The decision was announced on the Instagram account of the Secretary of Water Resources of Ceará (Figure 10). Soon after that, work began on the construction of the pipeline connecting the reservoir to the nearby city. This event confirms some of the challenges of the inclusion of communities in decisions around water allocation and in the design and implementation of water infrastructure (see García and Bodin, 2019, for some of the barriers to inclusion in Brazil).

Figure 10. Announcement on social media of the water transfer project from Cachoeira reservoir to Pedra Branca city.

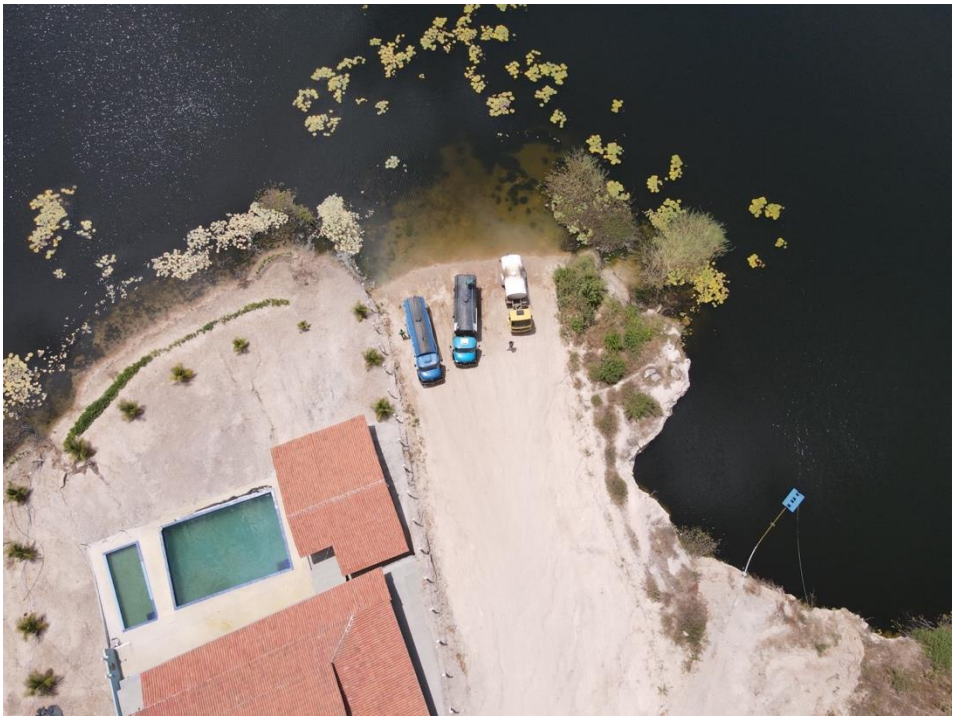


Source: Instagram account of the Secretary of Water Resources of Ceará (2022).

Cachoeira reservoir now provides water to Pedra Branca city through a pipeline and to rural communities in 6 municipalities via approximately 80 water tankers per day (Figure 11). Communities in Forquilha have mixed feelings about these transfers. They are proud to provide water to those in real need via water tankers but argue that water should only be distributed for domestic use and that the volumes concerned must not risk drying out the reservoir. The new pipeline to Pedra Branca is more controversial. A feeling of identity ('our water') emerged in discussions and interviews in September and October, 2022, and participants in a January 2023 workshop expressed feelings of inequity and dispossession. Are rural communities in Forquilha catchment being left without water? What local effects do water transfers to the city have? As members of the Cachoeira community commented in interviews, "We have no authority

over this reservoir. It's not our water (…) it's the state that decides (…) the inhabitants of Pedra Branca really need it, as we saw on TV and they also talked about it on the radio (…)". The reaction of the communities was thus clearly expressed in the question asked by Lemos (2009): "Whose water is it anyway?"

Figure 11. The Cachoeira do Germano reservoir and its different uses.



Source: Drone photo by Letícia Vieira (2023).

Note: The reservoir supplies water to: 1) six municipalities by water tankers (from Monday to Saturday); 2) two community networks (the small blue pump to the right of the picture); 3) a nearby city through a pipeline; and 4) leisure activities (swimming pools, fishing, recreation).

According to local inhabitants, the pipeline construction has been supported by stories and discourses on local radio channels, TV news, and social media about the neighbouring city's severe water crisis. These stories implied that communities had a moral duty to collaborate in solving that crisis, for example by not contesting the transfer pipe to the city. This points to a strategy of establishing social and ethical norms to accompany the infrastructure project; in this case the media helped justify the rural – urban water transfer (Hommes et al., 2020). The construction of pipes and the use of a powerful pump leaves the population worried that the reservoir will dry up and feeling that they have lost all control over the water. At the same time, because of promises made during a recent political meeting (Figure 8), the inhabitants of the Forquilha catchment are hopeful that a new pipeline will be installed which uses the new pumps to supply the entire Forquilha catchment with domestic water from the Cachoeira do Germano reservoir. It remains to be seen whether that promise will be fulfilled.

What we can observe from this story of the water transfer is that it has led to a rediscovery of catchment interdependence among the various communities that had been focusing so much attention on formal and informal water access at the level of households, nucleated settlements and communities. Workshop participants expressed a loss of control over water sources, which may affect water security in various ways for different communities. The question is then whether this renewed sense of

interdependence may give rise to new forms of water ownership, collective action and, as a consequence, new hydrosocial territories.

The viewpoint of the institutions: Hydrosocial territories organised around reservoirs in the upper catchments

Rural communities' internal arrangements to maintain functional water supplies are invisible to larger institutions. The role of the state is to provide water infrastructure and it is then the responsibility of the community to manage the water systems. In a context of pressing water shortages in cities, water resources in the upper catchments have become more visible to institutional actors. This was noted in a 2022 workshop with institutional stakeholders, during which three separate working groups were asked to define and limit, according to their opinion, what constitutes hydrosocial territories (HSTs) in the Forquilha catchment.

The three working groups thus identified three rather similar HSTs organised around medium-sized public water reservoirs in the upper catchment of Forquilha (see Appendix 2). These reservoirs were considered crucial for local uses (irrigation, drinking water and domestic use); however, they are also increasingly being seen as strategic resources for the transfer of water to cities. The territories were very different from those identified by the communities themselves (Figure 7), as the working groups (made up of representatives of institutions) focused on the water resources that could be obtained for transfer from the Forquilha catchment. All three working groups, however, paid particular attention to conflicts inside the territories. In fact, state water institutions have the legitimacy and the power to interfere as mediators in the solving of water-related conflicts; they thus have the authority and regulatory power to extract water and shape water territories by controlling water infrastructure (Hoogesteger et al., 2016). They also, however, have to deal with intricate social relations particularly in cases of water transfer, and experience has taught them to be very attentive to these relations. In our case, the fact that the three upstream reservoirs had been constructed by the state and that they were being partly used to fill water tankers legitimised further intervention in the form of the construction of a pipeline to feed a neighbouring city. State services have their own vision of how water and water users should be territorialised, with a clear priority on the provision of drinking water to cities. As we showed previously, however, the fact that six hydrosocial territories had progressively come into being in the Forquilha catchment also made the communities less united in their stance towards the state-led abstraction of water, to the benefit of the city of Pedra Branca.

CONCLUSION

Formation of hydrosocial territories for sustainable water access in rural communities

The paradigm shift from the hydraulic era to 'living with drought' in Brazil's Nordeste has led to the massive expansion of decentralised water infrastructure at the community and household levels (Formiga Johnsson and Kemper, 2007). The idea is to build on "the innovative capacity of peasant families", thus "creating a socio-ecological system with great resilience" (Mattos et al., 2022: 33). This paradigm shift has been manifested in the development of community water supply networks for drinking water, cisterns for drinking water and small-scale productive activities (fish farming, gardening), and boreholes and small reservoirs for irrigation and watering livestock (Gutiérrez et al., 2014; Mattos et al., 2022). The decentralisation of water infrastructures, however, resulted not only from state or NGO programmes. We showed that an impressive number and diversity of small-scale water infrastructures have been implemented by households, nucleated settlements and communities in the Forquilha catchment, as elsewhere in Ceará. This plurality of small-scale infrastructure for multiple purposes (see Smits et al., 2010), reduces their dependence on a single source that may dry up at some point, or on a single actor or organisation. For instance, families avoided relying exclusively on community associations, some of

which have experienced serious organisational problems, or on the state and its water tankers; instead they built individual reservoirs, dug wells, and/or drilled boreholes.

State- and NGO-led programmes of small-scale water supply infrastructure alongside private individual and collective initiatives have woven a dense web of water reservoirs, wells and boreholes, pipes and taps; these are shaped by, and also reshape, social structures and networks. We have shown how these diverse initiatives have influenced the formation of a multitude of hydrosocial territories in Forquilha catchment; we have revealed the multiple and dynamic set of interactions between infrastructures, water flows and social networks (Boelens et al., 2016). Within these territories, there has been improvement in sustained access to water for (most) rural households and therefore enhancement of the resilience aimed for by state- and NGO-led programmes. Not all community associations were equally active, which may account for variations in the functionality of community networks. No families in Forquilha catchment communities, however, relied exclusively on these community water supply networks; instead, they favoured multiple water sources and infrastructures that were linked to multiple actors through formal and informal arrangements. Sustained water access is thus a social construct that results from a plurality of strategies and dialogues among stakeholders in a rapidly changing (water) environment; it challenges the "intended hydrosocial fix" whereby water infrastructure is implemented through formal arrangements (Hommes et al., 2022).

Our analysis of the relational networks around the implementation and use of small-scale water infrastructure also showed that households and communities invested in institutions and arrangements, enabling the operational functioning of community domestic water supply networks while guaranteeing a certain solidarity among households, especially for drinking water but also water for agricultural uses at the NS level. We also observed the strong relations that communities maintain with outside actors around decentralised infrastructure (including state representatives, politicians and NGOs) despite the explicit community focus of rural water supply programmes (Enéas da Silva et al., 2013). Despite state efforts to eliminate clientelism, for instance (Collard, 2013), politicians were often mobilised to contribute to finding solutions when water supplies failed, as demonstrated by the Varzeo do Meio community. Such arrangements are part of the messy and contested processes through which infrastructure and territorial relations co-evolve (Obertreis et al., 2016), even if clientelism is often challenged by scholars and activists (Nelson and Finan, 2009). Yet without such relations, it is very difficult to maintain access to water. At the same time, the interactions among community representatives during the workshops showed that not all communities are successful in mobilising outside actors. Indeed, some communities and households still have weak access to water, in particular households that have only recently settled in the catchment.

Fragmenting basins, fragile communities?

We have shown in this paper the dynamic nature and flexible geographical boundaries of hydrosocial territories, which are subject to change and transformation (Hommes et al., 2022). While it can be argued that the formation of small community-based hydrosocial territories has improved the sustainability of water access for families in the Forquilha catchment, it is important to also consider how infrastructural interventions have changed water flows and social relations at other scales (Hoogendam, 2019). In the case of Forquilha, this has led to the loss of hydraulic connectivity and the fragmentation of the catchment area through the formation of smaller hydrosocial territories. It has weakened social linkages around water while contributing to water shortages in downstream strategic reservoirs.

The community focus on water infrastructure development by the state led indirectly to three different but interrelated phenomena that show the central role of water infrastructure in shaping hydrosocial territories. First, there was a fragmentation of the Forquilha catchment into multiple small hydrosocial territories, and water infrastructure is now considered to be linked to single communities. Community reservoirs have become part of the identity of rural communities and indeed are often named

after them. According to Freire and Calijuri (2011: 681), they are sometimes referred to as "waterworks of coexistence with (…) drought". Even medium-sized reservoirs in the upstream part of the catchment have been appropriated by nearby communities and 'our water' is the discourse generally used by upstream communities members for such reservoirs. Despite several attempts, the more distant downstream communities have not succeeded in obtaining access to these reservoirs and water flows in the Forquilha River have been disrupted, resulting in a loss of hydraulic connectivity. This has prompted downstream communities to lay claim to a reservoir as 'theirs' in order to guarantee future water availability; in one case they were able to construct a new reservoir for use by their community (see Mosse, 1997).

Second, decentralised water infrastructure has become a massive phenomenon in the Nordeste with the construction of thousands of boreholes and reservoirs, most of which are below the radar of the state (de Araújo and Medeiros, 2013). This decentralised water infrastructure has vastly expanded stable water access, thus encouraging farmers to increase the amount of water they use for livestock and/or to adopt more intensive forms of irrigation. This, combined with climate change, has reduced inflows into the large so-called strategic reservoirs (ibid), which has, in turn, challenged the urban drinking water supply.

Third, and perhaps paradoxically, the over-development of small-scale water infrastructure in upstream catchments such as Forquilha has combined with the community focus of the infrastructural programmes to create the conditions for the state to become more closely involved in catchment affairs. The state gained a strong motivation to act (severe water shortage in urban areas), while the social cohesion between Forquilha communities was weakened through the creation of autonomous small hydrosocial territories. The state renewed its interest in some of the medium-sized reservoirs in upper catchments. The analytical lens of hydrosocial territories is particularly enlightening with regard to the dynamic and multi-scalar nature of hydrosocial territory and its contested nature linked to the diverging perspectives of the different stakeholders (Obertreis et al., 2016). The main stakeholders – the state and the upstream and downstream communities – had a radically different perspective on the hydrosocial territory and on the productive function of the reservoirs in the upper catchments. The Forquilha case clearly shows how hydraulic infrastructures have shaped power and moral relations, which has led to the transfer of water to urban areas. A similar case was reported by Hommes et al. (2020: 417) in Mexico, where "[w]ater technology is moralized, to the benefit of the city and affluent social actors (while, simultaneously, rendering these unequal social relations invisible)". As we have shown, in a context of fragmented water flows and hydrosocial territories, communities were quite powerless in their negotiations with the state (Hommes and Boelens, 2017). In the absence of such negotiations and without regulatory arrangements that give voice to rural communities, state projects that connect water flows at different levels may lead to processes of dispossession of water, and livelihoods, of vulnerable groups.

Given their dynamic character, the present hydrosocial territories are likely to be reshuffled, in particular by state transfers of water to neighbouring catchments. In a semi-arid region struck with repetitive droughts, the state's covetous approach is well-represented by an institutional view that sees a catchment as being organised around its upstream reservoirs. We have also shown, however, that transformations of hydrosocial territories will not be homogeneous across the catchment because of the diverse sociopolitical and water realities (see Hoogendam, 2019). Moreover, a renewed appreciation by communities of the interdependence within the catchment is certainly going to play a role in these transformations.

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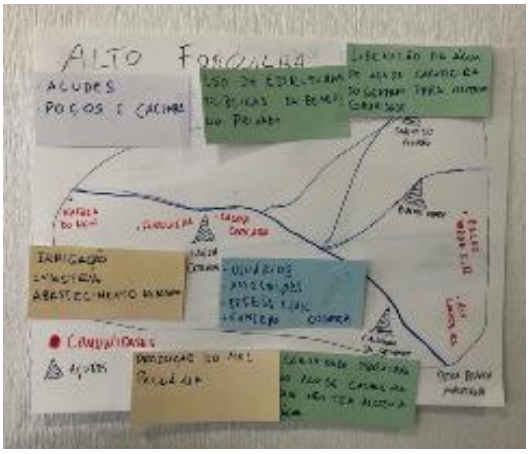
Appendix 1. Water infrastructure and uses in six hydrosocial territories of Forquilha catchment in 2022

Hydrosocial territories	Communities	Water infrastructure	Uses
1	-Cachoeira do Germano -Riacho Verde 1 -Riacho Verde 2	- Two medium-sized collective reservoirs in Cachoeira and Riacho Verde 1 - Individual reservoirs (47) - Collective well in Riacho Verde 2 (1) - Individual wells, boreholes (9) - Individual cisterns*	- Domestic use and irrigation of fodder crops around reservoirs - Cachoeira reservoir supplies other households in the catchment, but also households outside of the catchment (by water tanker) -No irrigation due to scarcity of land
2	-Riacho do Algodão -Quandu	- Small collective reservoir (Riacho do Algodão) - Individual reservoirs (42) - Collective wells (1) -Individual wells (3) for cattle and fodder crop irrigation - Individual cisterns	-Both communities are supplied by the same community water supply network connected to the reservoir -Individual wells for cattle and to irrigate fodder crops
3	-Jardim -Varzea Formosa -Lagoa Cercada -Trapiazeiro	-Two small collective reservoirs (Jardim and Lagoa Cercada) - Individual reservoirs (44) - Individual wells (18) and boreholes (21) - Collective wells (4) - Individual cisterns	-Jardim and Lagoa Cercada communities have access to groundwater and surface water for domestic and agricultural use -Varzea Formosa and Trapiazeiro only have access to groundwater for domestic and agricultural use -Individual wells and boreholes for cattle and to irrigate fodder crops
4	-Forquilha -Malhadinha -Varzea do Meio -São Bento 2	- Small collective reservoir (Varzea do Meio) - Individual reservoirs (72) - Collective wells (3) - Individual wells, boreholes (41) - Individual cisterns	-Biggest consumers of water in the catchment to irrigate fruit trees, beans and maize -Many cattle breeders (intense production of silage and fodder)
5	-São Bento 1 -Veneza	- Ford in Veneza - Individual reservoirs (37) - Collective wells (2) - Individual wells, boreholes (10) - Individual cisterns	-Watering livestock and irrigation -São Bento relies on wells and benefits from a ford, facilitating the aquifer recharge
6	-Boa Vista -Agreste -Campinas	- One collective reservoir in Campinas - Individual reservoirs (37) - Collective well (2) - Individual wells, boreholes (6) - Individual cisterns	- Watering livestock

*Almost every household has a cistern

Appendix 2. Hydrosocial water territories in the Forquilha catchment as identified by institutional actors in three working groups

Hydrosocial territory identified	Explanation given by the three working groups
Group 2.1. The hydrosocial territory was delimited around the area of the Cachoeira do Germano reservoir. 	This is a medium-sized reservoir that supplies communities in the vicinity and immediately downstream of the reservoir. The reservoir is monitored by the state and currently a pipeline connects it to a nearby city. The reservoir has several uses: irrigation, supplying drinking water, supplying water trucks, and enabling fish farming. There are potential conflicts between upstream and downstream communities in the catchment. Tensions emerged in the catchment because of water transfer to the city.
Group 2.2. The hydrosocial territory encompasses the area reaching from the headwaters of Forquilha River to the Varzea do Meio community. 	The group focused on the upper catchment (Alto Forquilha) as an area with "good water capacity". Strategic medium-sized reservoirs in the catchment ensure a continuous flow in the river and recharge the aquifer. The presence of a pipeline transferring water to a nearby city led to a number of conflicts in the region. Many different water resources and infrastructures exist including reservoirs, wells and shallow dug wells. Water uses include irrigation, industry, drinking water supply, honey production, agriculture and livestock. Conflicts arose because communities near Cachoeira reservoir do not have direct access to the water even though water is released from the reservoir to supply other communities, and because public infrastructure is used for private profit.
Group 2.3. The hydrosocial territory is linked to two strategic reservoirs in the catchment (Riacho Verde and Cachoeira dos Germanos).	A water territory (*territorio da agua*) was demarcated, and justified, by its water potential; it was limited to three upstream communities (Cachoeira, and Riacho Verde 1 and 2) and partially extended to the Jardim and Riacho do Algodão communities. Participants declared that management of a larger area was not feasible as the region is densely populated. Water uses include drinking, extensive irrigation, watering livestock, fish farming and filling water trucks. Problems and conflicts are related to indiscriminate recreational

use, use of agrochemicals, and deforestation of the strip bordering the reservoir.