The Professional Geographer

ISSN: 0033-0124 (Print) 1467-9272 (Online) Journal homepage: https://www.tandfonline.com/loi/rtpg20

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Urban water security strategies commonly pivot around supply-side initiatives to mitigate scarcity, forecasted population growth, or anticipated climate change; yet, scholars have begun to expand urban water security scholarship by including alternative frameworks that incorporate equity into the analysis. Our study seeks to contribute to this equity turn by opening the investigative aperture on urban water security research in several aspects. We address the question of water security for whom, and turn our attention to the urban resident and household. We shift empirical focus to smaller urban centers in the Global South, and we develop a new assessment tool for water insecurity, the Household Water Insecurity Index (HWISI), to assess differences across the urban waterscape. We conducted this research in Forquilha (Ceará, Brazil), which represents an overlooked class of small urban centers common across Brazil's semiarid region. We draw on qualitative and quantitative data to describe household water insecurity using the HWISI. The prevalence of household water insecurity is variable, with a quarter of the population experiencing moderate to severe household water insecurity. In addition, analysis of the factors within the HWISI demonstrated how specific water insecurity domains push households across water insecurity thresholds. **Key Words: Brazil, drought, equity, household water insecurity, semiarid, urban**。

城市水保障措施一般是基于来自供水方的短缺调节、人口增长预测或气候变化预测。然而专家们已经把城市水保障研究拓展到了能包括公平的其它框架。我们的研究将在几个方面为城市水保障研究提供新的思路，旨在公平上的研究有所贡献。我们讨论了水保障是为谁的问题，关注的对象是城市居民和家庭。我们把焦点转向发展中国家较小的城市中心，开发了一个新的水危险评价工具（家庭水危险指数，HWISI）来评价城市水环境的差异。我们的研究区在巴西Ceara州的Forquilha市，是在巴西经常被忽视的半干旱地区小城市中的一个。我们用定量和定性方法，描述了基于HWISI的家庭水危机。研究发现，家庭水危险呈不均衡状态，四分之一的人口面临中度到重度的危险。另外，HWISI因子分析表明，某些特定的水危险指数可以导致完全的水危险。 **关键词：巴西，干旱，平等，家庭水危险，半干旱，城市。**

Las estrategias de seguridad hídrica urbana comúnmente giran alrededor de iniciativas por el lado de suministros para atemperar la escasez, el crecimiento demográfico pronosticado, o el cambio climático que se anticipa; no obstante, los estudiosos han empezado a ampliar la erudición relacionada con seguridad hídrica urbana incluyendo marcos alternativos que incorporan la equidad en el análisis. Nuestro estudio busca contribuir en este giro hacia la equidad extendiendo la apertura investigativa sobre la seguridad hídrica urbana en varios aspectos. Abocamos la cuestión sobre seguridad del agua para quién, y volvemos nuestra atención hacia el residente urbano y el hogar. Cambiamos nuestro foco empírico hacia centros urbanos más pequeños del Sur Global, y desarrollamos una nueva herramienta de evaluación para determinar la inseguridad hídrica, el índice de Inseguridad Hídrica del Hogar (HWISI), para evaluar diferencias a través del paisaje hídrico urbano. Realizamos esta investigación en Forquilha (Ceará, Brasil), localidad representativa de una clase ignorada de centros urbanos pequeños, de común ocurrencia a través de la región semiárida del Brasil. Nos basamos en datos cualitativos y cuantitativos para describir la inseguridad hídrica de los hogares usando el HWISI. Es variable la prevalencia de inseguridad hídrica en hogares, con un cuarto de la población experimentando inseguridad hídrica, entre moderada y severa, en los hogares. Además, el análisis de los factores dentro del HWISI demostró de qué manera específica se empujan los dominios de la inseguridad hídrica a través de los umbrales de la inseguridad hídrica. **Palabras clave: Brasil, equidad, inseguridad hídrica de hogares, semiárido, sequía, urbano**。

Urban water security strategies commonly pivot on supply-side initiatives to mitigate scarcity, forecasted population growth, or anticipated climate change (McDonald et al. 2014). In the Global South, urban water security research largely follows the parameters of techno-managerial strategies, almost exclusively attending to water for large metropolitan regions (Krueger, Rao, and Borchardt 2019). In Brazil, urban water security research follows the goal-oriented, supply-side model by interrogating the technological and governance challenges of failing reservoir and utility systems for megacities (Jacobi

The Professional Geographer, 0(0) 2020, pages 1–18 © 2020 by American Association of Geographers..
Initial submission, July 2019; revised submission, October 2019; final acceptance, December 2019.
Published by Taylor & Francis Group, LLC.

et al. 2013; de Souza et al. 2017; Petelet-Giraud et al. 2018; Empinotti, Budds, and Aversa 2019). As Hoekstra, Buurman, and van Ginkel (2018) rightly pointed out, however, "The question 'security for whom' often remains unanswered" (6).

Recently, scholars have begun to expand urban water security scholarship by leveraging alternative frameworks that incorporate equity (Zeitoun et al. 2016). Others call for a reconstitution of how security is defined and seek to extend critical analysis beyond the urban infrastructure to include interdependent hydrosocial securities and systems (e.g., food security, energy security; Zeitoun 2011). Scholars have argued for new perspectives to examine how urban water security strategies unequally transform the urban and rural gradient into new hydrosocial territories (Boelens et al. 2016; Beckner et al. 2019; Hommes et al. 2019). Torio, Harris, and Angeles (2019), for example, recently proposed the idea of a "rural–urban water equity nexus," illustrating how water governance decisions compound existing inequities in drinking water provision across urban and rural areas.

Our study seeks to contribute to the equity turn in urban water security research by opening the investigative aperture in three distinct ways. First, we address the question of water security for whom, and turn our attention to the urban resident. An analytical switch to water demand allows us to examine interactions between urban water governance and the cascading and variegated consequences for household water insecurity. Rather than adopt the supply-side orientation of "water security" frame, our focus is on "insecurity" because it speaks directly to the question of equity and experiences underpinning our demand-side analysis at the household scale. We adopt a conceptual framework that integrates multiple dimensions of household water insecurity, which underscores the interacting, copresent, uneven, and cumulative physical and psychosocial experiences of hydrosocial relations (Jepson, Budds, et al. 2017). Thus, our broad framing, advocated by Cook and Bakker (2012), allows for a holistic water insecurity analysis that addresses the complex intersection of water in everyday urban life that might cumulatively (and unevenly) erode the human right to water (Jepson, Wutich, and Harris 2019).

Second, we turn our attention toward the challenge of water insecurity outside major metropolitan areas and coastal capitals to largely marginalized and smaller urban centers, which have fewer resources to respond to increasing external pressures on water resources and often lack expertise and managerial talent to manage water and sanitation systems (Montgomery 2008; Adamo 2010). Although large cities merit attention, the empirical basis for developing theories and analytics are profoundly biased toward the extreme examples from large metropolitan areas (Garmany 2011). This bias obscures divergent challenges of urban water insecurity in smaller, more remote, and vulnerable regions, often outside the view of the research community. Therefore, we argue for the importance of diversifying our empirics as we think more critically about how to develop concepts of water inequities more broadly. In Brazil's drought-prone semiarid region, for example, 9.2 million people live in cities smaller than 50,000 residents, and another 1.5 million people live in urban areas with between 50,000 and 100,000 residents (Instituto Brasileiro de Geografia e Estatística. 2011). For this study, we examine a small urban center (< 50,000) in Brazil's semiarid region to assess household water insecurity during the last major drought (2011–2017).

Third, we are concerned with advancing the emerging scholarship on household water insecurity metrics (Jepson, Wutich, et al. 2017), because such metrics provide an empirical basis from which we can develop longitudinal studies that track patterns of distributional inequity through various scenarios of institutional, climatic, and economic change. Most household water insecurity metrics have expanded beyond a single domain to address a broader set of domains (Wutich and Ragsdale 2008; Stevenson et al. 2012; Jepson 2014). Tsai et al. (2016) validated a Household Water Insecurity Access Scale (HWAIS) for rural Uganda that has been a benchmark tool for subsequent studies, even as others have made a strong case for cross-cultural metrics for global benchmarks (e.g., SDG 6; Young, Boateng, et al. 2019; Young, Collins, et al. 2019). For the purposes of this study, we build an empirical model of household insecurity as an important first step toward developing a validated regional tool for Brazil's semiarid northeast region such that we can address distributional inequities at the household scale. A regional tool for assessing water insecurity in the semiarid region complements global, cross-cultural metrics and offers more specific contextual information for policymakers to develop targeted policy interventions.

This article details the cumulative challenges of urban water security from the perspective of the household to provide a comprehensive assessment of these experiences during drought for an underresourced and vulnerable urban community. By quantitatively analyzing water insecurity at this scale, we also provide important information on variability across households, offering a clear assessment of how drought exacerbates inequity in small urban areas. We also provide the first household water insecurity analysis using an index, the Household Water Insecurity Index (HWISI), to compare the specific domains of water insecurity. Analysis of the index subcomponents reveals dominant factors or domains that push households across water insecurity thresholds. This information offers insight into potential policy and urban water resilience interventions that could be most effective and equitable during times of

Figure 1 *Urban residents washing clothes in public spring.*

severe drought for the semiarid region of Brazil. Rather than default to generic supply augmentation, household water insecurity information could lead to targeted interventions, such as water affordability programs and better management and control of public standpipes paired with water quality interventions.

Data and Methods

Study Region: Forquilha, Ceará

Drought has shaped the livelihoods, landscape, and society in Brazil's semi-arid northeast for most of the twentieth century (Arons 2004). The Brazilian government has implemented several policy regimes to either combat or coexist with this climatological reality for decades. Social programs, built on long-standing systems of clientelism, have targeted rural communities (Kenny 2002; Nelson and Finan 2009), and large cities have benefited from major infrastructure investments to secure water supplies (Buckley 2017). Yet, continued drought risk under climate change increasingly places pressure on the region's existing physical infrastructure and governance capacity to manage water for cities (Chou et al. 2014; Fonseca et al. 2017). Recent drought in northeast Brazil (2011–2017) revealed significant weaknesses of existing urban water systems (Azevedo et al. 2018; Marengo et al. 2018), indicating that future climate change could further erode the sustainability of urban water systems.

Although the state of Ceará has one of northeast Brazil's largest water storage, distribution, and management infrastructures (Rocha et al. 2011; Gutiérrez et al. 2014), urban populations remain vulnerable to periodic droughts. Large metropolitan areas are prioritized over smaller urban centers (de Freitas 2015; Roman 2017; Empinotti, Budds, and Aversa 2019). Moreover, not all urban populations have equal access to the benefits of urban water systems. Socially and economically marginalized households are forced to develop diverse strategies for domestic urban water provision, including tanker trucks (*carros-pipas*), bottled water delivery, public taps, and unregulated wells (Caprara et al. 2009), whereas some use water holes for laundry (Figures 1 and 2).

We conducted our study in the urban center of Forquilha (population of about 20,000), a municipality that is representative of many areas in the semiarid interior (Figure 3; Argao and Loilola 2006). Forquilha provides basic services for residents and adjacent rural populations. Almost 99 percent of residents are connected to a public water supply system. Most residents meet the international bench marks of improved water access defined by the Joint Monitoring Programme (JMP). Yet, like many others supposedly connected to water utilities, everyday experiences of water insecurity persist, and for some, worsen under drought.

Figure 2 *Waiting for water at a public tap.*

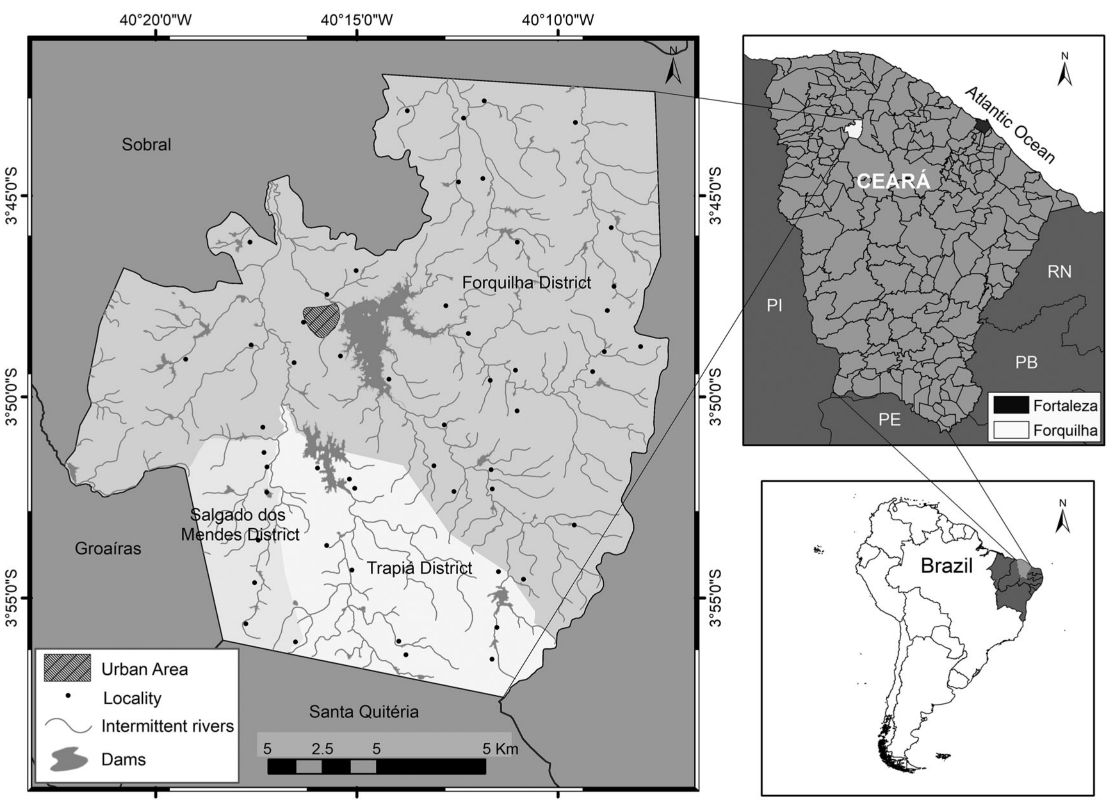


Figure 3 *Study site location.*

Companhia de Água e Esgoto do Estado do Ceará (CAGECE) is the publicly owned water corporation that runs the water supply system serving Forquilha's urban population. This reservoir-supplied water system continued until 2007, when the urban center experienced a major water crisis. During that year, CAGECE did not have the capacity to treat the reservoir water. The residents lost service for several months. Local government initiated emergency measures, such as drilling wells and organizing water distribution by tanker trucks; however, these alternatives left hundreds of residents waiting for hours to access water from standpipes supplied by new wells. In response to the 2007 through 2009 water supply crisis, the municipality built the Forquilha aqueduct, a 20-km pipeline that captures water from the Acaraú River (Rabelo et al. 2012), and suspended use of the reservoir for the public network.

With the 2011 dry season, however, the reservoir's water supply and quality decreased precipitously. Two years into the drought, urban dwellers began to struggle with household water provision. With declining water levels, the population expressed concern about water pollution and water supply. In July 2015, community members announced in the media that they had gone more than two months without receiving water. In the first half of 2015, the Acaraú River stopped flowing permanently, thus closing the pipeline to Forquilha. Once again, the municipal government was not prepared, and the solution was to implement other emergency measures. By August 2015, CAGECE again drew water from the Forquilha reservoir, which at the time was at less than 5 percent capacity. With the transfer of the water intake system from the Forquilha reservoir, it was necessary to change the water treatment system, as technical reports indicated hypereutrophication and large amounts of cyanobacteria. CAGECE did not guarantee that the water was potable, as was verified in the interviews with the water managers. In addition, CAGECE published the Forquilha Rationing Plan in September 2016, when the reservoir was at 2.80 percent capacity (CAGECE 2016). Despite these efforts, the water managers and city officials could not meet the water needs of the urban population until drought began to wane in 2017.

Household Survey and Sampling

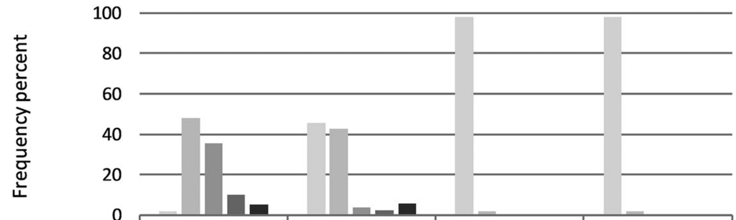
The household survey included modules covering (1) sociodemographics, (2) water access and sanitation, (3) water storage and treatment, and (4) household water insecurity experiences. All questions were asked using two recall periods: the previous four weeks and previous four months. The survey enumerator also asked open-ended questions on water insecurity experiences, which were transcribed and included in the data set. We used a broad set of survey items developed in conjunction with the Household Water Insecurity Experiences Scale project (Young, Collins, et al. 2019). This collaboration ensured that the survey items represented various dimensions of household water insecurity that were pretested by an international panel of experts. The survey was also pretested with local individuals who underwent cognitive interviews to ensure question interpretation and language. All questions in this article are translated from the Portuguese, the language of the original survey. In our pretesting phase, we determined that a recall period of four months was best understood and accepted by the respondents.

Household surveys were administered in May to July 2017, a period of severe drought. The Forquilha municipality has 6,157 households; therefore, our power calculation yielded a target sample of 258 (confidence interval of 90 percent and sample error of 0.5). Results reported here are part of a larger study that included rural areas; thus, the sampling required that we cover all households proportionately between urban and rural areas. We exceeded our urban sampling target ($N = 177$), with 221 households distributed across the city.

Creating a Household Water Insecurity Index

For this study, we also developed an index to integrate water insecurity dimensions into one metric called the HWISI. We ran several tests to verify the appropriateness of our statistical procedures. First, we checked internal consistency of the data set using Cronbach's alpha (0.806), which was acceptable. We then ran a Bartlett's test of homogeneity of variances (Bartlett's $\chi^2 = 231$, $p < 0.001$), and a Kaiser–Meyer–Olkin test (KMO = 0.707) for proportion of variance, which confirmed that the data distribution was appropriate for factor analysis.

We used a principal components analysis (PCA) to extract factors, and then we used a Kaiser criterion to ensure that all assumptions were fulfilled such that we could extract factors. The first eight factors with eigenvalues greater than one, a statistic used to decide on factor retention, explained a total of 71.06 percent of variance. These eight factors were named according to the characteristics of the variables and domains of water insecurity with significant loads. Using the factor scores, we then calculated the HWISI.[1] After the calculation of the index, we standardized the value where the best performance regarding the indicator (e.g., lowest water insecurity) acquires the value of 0 and with the worst performance (e.g., highest water insecurity) the value of 1. To classify the severity of water insecurity for further analysis, we conducted a cluster analysis. We applied the nonhierarchical K-mean agglomeration to create four clusters of water



	% Drinking	% Cooking	% Domestic Activities	% Bathing
Pipes	1.8	45.7	98.2	98.2
Protected Well/Public Tap	48	42.5	1.8	1.8
Bottled Water	35.3	3.6	0	0
Rainwater	9.9	2.3	0	0
Other	5	5.9	0	0

Figure 4 *Domestic water source and use.*

insecurity (marginal, low, moderate, severe; Jepson et al. 2014). With the formation of four classes, the one-way analysis of variance (ANOVA) F test was used to verify whether the variability between the classes is significantly higher than the internal variability in each class. Finally, we compared mean factor values and ran correlation analysis to determine what statistically significant associations could be identified between certain sociodemographic factors and index.

Results

Experiences Beyond the Tap

Although the public water supply system is connected to 98.2 percent of respondents, the reliability of this source for human consumption eroded during the drought, and urban residents sought other options. Over 75 percent of respondents collected water from public taps (*chafirizes*) drawn from protected wells built by the municipality. Although ten wells were distributed throughout the city, only three provide desalinated water suitable for human consumption.

As the urban water crisis progressed from 2011 to 2017, it spurred a private water market, consisting of authorized water vendors, who sold water in 20-liter bottles, and unauthorized water vendors selling water from the public tap and private sources (unprotected and protected wells). Often water was conveyed and stored in 20-liter containers or 100-liter plastic containers that were repurposed from agrochemical use. Just over half of the urban residents (51.0 percent) bought authorized bottled water, and over a quarter (27.6 percent) bought bottled water from informal vendors. Field research also revealed that during this drought unauthorized water vendors collected water from the public taps—often placing multiple water containers (sometimes more than twenty) or jerry cans in line—to access and profit from public desalinated water for resale in neighborhoods farther away. Some interviewees witnessed altercations and threats of violence if residents challenged these practices.

Urban residents varied in their water use depending on the source and perception of what they considered to be suitable for consumption (Figure 4). Few respondents (1.9 percent) consumed water from the public system. Instead, the respondents' drinking water came from public taps (protected well; 48.0 percent), bottled water (35.0 percent), rainwater (9.9 percent), and water trucks (5.0 percent). We also noted that households relied on multiple water sources for single purposes. For drinking water, 52.5 percent of households cited at least two water sources and 18.0 percent cited at least three. In addition, the perception of water quality determined the use of water sources.

Households reported three months of water shortages, concentrated between August and December, although they also noted unpredictable intermittency every month, with 47 percent of households reporting that the water supply had been interrupted (Table 1, Q2). Intermittent water availability intersects with household practices. For household chores, like washing dishes, washing clothes, and cleaning house, water from the public systems dominated at 98.2 percent, and only 1.8 percent used water from the public tap. This pattern also matched water use for personal hygiene. For example, 35.7 percent of households did not have enough water for daily use such as cooking, cleaning, drinking, and other uses (Table 1, Q1). In some homes, water was lacking even for basic hygiene, with 11.8 percent of those interviewed confiding that they had not taken a shower because there was no water (Table 1, Q7). Water access problems prevented over one quarter of the households from

Table 1 *Water supply, use, and availability*

Question	Variables	Frequency (%) 0	1–2	3–10	11–20	20+	Total
1	In the last 4 months, how often has your home not had water for daily use (cooking, cleaning, drinking)?	64.3	16.3	13.1	5.4	0.9	100
2	In the last 4 months, how often has the water supply from your main water source been interrupted?	62.0	18.1	12.2	6.3	1.4	100
3	In the last 4 months, how often did the time spent getting water prevent you or anyone in your household from caring for children in the home?	37.6	2.3	3.2	1.4	1.4	45.9
4	In the last 4 months, how often did children drop out of school for lack of water?	94.0	2.3	2.3	1.4	0.0	100
5	In the last 4 months, how often was not there enough water in the house to wash clothes?	73.7	12.7	8.6	3.2	1.8	100
6	In the last 4 months, how often have you or anyone in your household had to change food intake because there was not enough water?	91.9	2.7	3.2	0.9	0.9	99.5
7	In the last 4 months, how often have you or anyone in your household went without a shower because there was not enough water?	88.2	6.3	3.6	1.4	0.5	100
8	In the last 4 months, how often have you or anyone in your family borrowed other people's water?	72.4	10.4	10.9	4.1	2.3	100
9	In the last 4 months, how often have you or anyone in your family lent water to anyone?	59.7	18.1	15.8	3.6	2.3	99.5
10	In the last 4 months, how often has not there been enough water to drink as you would like for yourself or someone from your home?	83.7	8.1	5.4	1.8	0.9	100
11	In the past 4 months, how often have you or anyone in your household changed your routine because you had to solve a water problem?	77.8	16.3	5.4	0.5	0.0	100
12	In the past 4 months, how often have water issues prevented you or anyone in your household from attending social events in your community?	96.8	0.9	0.9	1.4	0.0	100
13	In the past 4 months, how often have physical limitations (because you are elderly, a child, or disabled) prevented you or anyone in your household from getting water?	84.6	5.4	2.3	0.9	6.8	100
14	In the last 4 months, how often have you or anyone in your household been unable to get water where they wanted because they were very sick or weak?	83.7	7.7	5.9	0.9	1.8	100

Table 2 *Availability of public water supply according to neighborhoods*

Neighborhood \ Variable	Public water availability: Continuous	Predictable intermittent	Irregular intermittent	Unreliable intermittent	Total
Antônio F. G. Martins	83.3	16.7	0	0	100
Centro	60	40	0	0	100
Mesquita Jerônimo	47.3	47.4	5.3	0	100
Edmundo Rodrigues	42	53	5	0	100
Francisco M. Viana	40.9	45.5	13.6	0	100
Alto Alegre	40	28.6	31.4	0	100
Padre Edson	25	37.5	37.5	0	100
Cidade de Deus	7.1	21.4	42.9	28.6	100
Pico da esperança	0	0	33.3	66.7	100

Notes: Continuous = the water supply is continuous with a relatively constant water pressure; predictable intermittance = supply characterized by water cuts that occur generally within a predictable and anticipated schedule, and with relatively constant water pressure during each delivery; irregular intermittent = intermittent supply arriving at unknown intervals within short periods of time of no more than a few days; water pressure might be inconsistent; unreliable intermittent = characterized by uncertain delivery times and the risk of insufficient water quantity, often exacerbated by limited storage and extended nondelivery times.
Source: Adopted from Galaitsi et al. (2016).

washing clothes (26.3 percent), with 13.6 percent of respondents reporting in the higher frequency categories over the recall period (Table 1, Q5). One respondent explained that the family had to travel to a rural area to wash clothes in the house of relatives who enjoyed greater water availability. Another respondent revealed that it was necessary to wash her school uniform at work instead of at home so as not to miss class. Some personal responsibilities had to be modified to accommodate the time and effort to get water at the public tap. Our data indicate that 8.3 percent of households stopped caring for children due to the time spent obtaining water. Some residents reported that they changed their routine to solve some water-related problem (22.0 percent; Table 1, Q3). This experience of water

Table 3 *Water costs*

Question	Variables	Frequency (%) 0	1–2	3–10	11–20	20+	Total
1	In the last 4 months, how often has the time spent obtaining water prevented you or anyone in your household from making money?	63.8	3.2	5.9	3.2	0.5	76.5
2	In the last 4 months, how often have you or anyone in your household not made purchases of other household goods to save money for water?	64.7	7.2	15.8	9.5	2.7	100
3	In the last 4 months, how often have you or anyone in your household not had the money to buy water?	63.8	5.4	13.6	13.1	4.1	100
4	In the last 4 months, how often has the time spent on getting water prevented you or anyone in your household from doing chores?	72.9	6.8	14.0	3.1	3.1	100

Table 4 *Water quality experiences*

Question	Variables	Frequency (%) 0	1–2	3–10	11–20	20+	Total
1	In the last 4 months, was the quality of water intended for human consumption unacceptable for consumption?	22.2	5.0	38.0	25.3	9.5	100
2	In the last 4 months, has the water quality of the public supply been unacceptable for use in household chores and cleaning?	77.4	6.3	14.0	1.8	0.5	100
3	In the last 4 months, have you noticed dirt or other small floaters in the public water supply?	54.3	13.6	25.8	5.0	1.4	100
4	In the last 4 months, have you smelled or smelled strongly from the water supply?	49.3	10.4	32.1	6.3	1.8	100
5	For the past 4 months, how often have you or anyone in your household drunk water that tasted bad?	65.2	14.0	14.0	5.9	0.9	100
6	In the last 4 months, have you noticed that the water was a different or cloudy color?	38.5	13.6	34.8	11.8	1.4	100

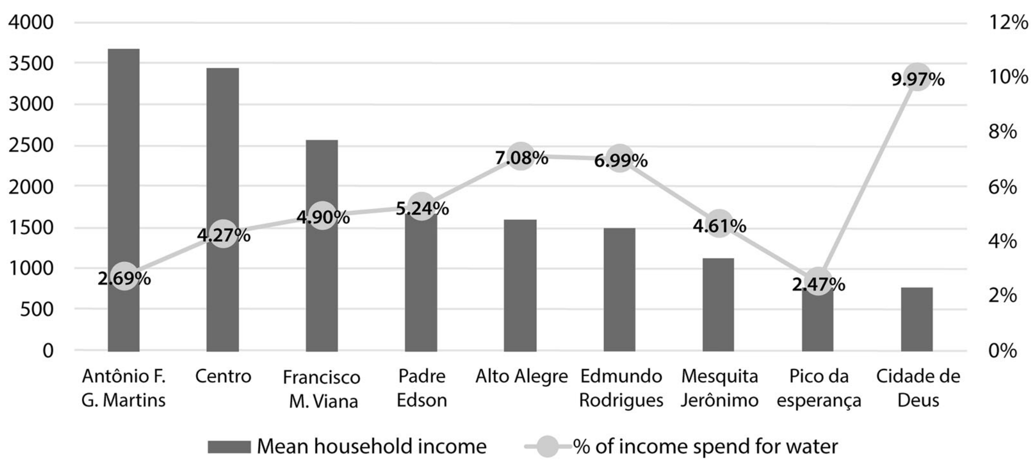


Figure 5 *Household water expenditures as a percentage of income.*

intermittency was not evenly experienced across the urban area, however. Irregular and unreliable intermittency was notable in only some of the neighborhoods (Table 2).

Water affordability also factored greatly in the everyday challenge of urban household water provision during this time of drought. Over one third of respondents (36.2 percent) reported that they did not have enough money to buy water (Table 3, Q2).

Table 5 *Water distress experiences: Frequency*

Question	Variables	Frequency (%) 0	1–2	3–10	11–20	20+	Total
1	In the last 4 months, how often have you or someone in your household become annoyed, worried, or afraid of not having enough water for all your household needs?	35.3	13.1	36.7	9.0	5.9	100
2	In the last 4 months, how often has it happened that you have become bothered, worried, or fearful about the safety of the person coming out to get water for the home?	58.4	7.7	24.9	5.0	4.1	100
3	How many times in the last 4 months have you been bothered, worried, or afraid to drink or use water?	66.1	13.5	16.3	2.7	1.3	100
4	In the last 4 months, how often have you or anyone in your household had water problems that have caused conflicts in the home?	87.3	3.2	6.8	1.8	0.9	100
5	In the last 4 months, how often have you had water problems that have caused conflicts with your water seller or supplier?	98.2	0.5	0.9	0.5	0.0	100
6	In the last 4 months, how often have you or anyone in your household been insecure about getting water out of the house?	71.5	10.0	11.3	5.0	2.3	100
7	In the last 4 months, how often did you think to leave your domicile because there was not enough water?	90.5	5.0	2.3	2.3	0.0	100

Table 6 *Water distress experiences: Level*

Question	Variables	Distress level (Frequency %) No	Troubled	Worried	Fearful	Total
1	In the last 4 months, have you or anyone in your household been bothered, worried, or afraid of not having enough water for all your household needs?	35.3	7.7	48.4	8.6	100
2	In the last 4 months, have you or anyone in your household been bothered, worried, or fearful about the safety of the person coming out to get water for the home?	58.4	7.7	31.2	2.7	100
3	In the last 4 months, have you or anyone in your household been bothered, worried, or afraid to drink or use water?	66.1	8.1	23.0	2.7	100

Other respondents had money to buy water, but it was expensive relative to their income, or they had to economize in other areas of household expenditures. Over one quarter of the residents also asked for water from neighbors or family members (27.7 percent; Table 1, Q8). Among the poorest households, 10.0 percent of their income was allocated for water for basic activities (Figure 5). Water was considered affordable in only one neighborhood (2.7 percent of monthly income). Economic trade-offs between water and other activities or goods emerged as an important dynamic in the daily life of the urban population. In some cases, respondents revealed that they did not have time to get water from the well because of work obligations.

Our data did not reveal new information about water quality, but rather confirmed that there were shared concerns. Water quality perceptions of tap water varied. About 80 percent of respondents reported that the water was inappropriate for use. Households reported unacceptable drinking water (78.0 percent), with the piped water as the cited source of poor-quality water (57.5 percent) considered to be unacceptable for human consumption (Table 4, Q1). In other circumstances, water from the network was inappropriate even for domestic activities (Table 4, Q2). In 22.6 percent of households, public water supply quality was unacceptable for use in household chores, and the main complaint was laundry. Data indicate that household management practices around water quality revealed a concern for safety.

Another dimension of household water insecurity is the labor required for water conveyance and water fetching. Figure 6 shows the frequency of the time spent to obtain water at public standpipes in each neighborhood, with the average time spent slightly above the JMP benchmark of thirty minutes (JMP 2019). Respondents indicated that many variables influenced the time spent to obtain water, ranging

Table 7 *Household water insecurity factors items (22)*

	Factor name	Factor components: In the last 4 months …	Variance (%)
Factor 1	Insufficient water supply	How often has your home had no water for daily use (cooking, cleaning, drinking)? How often has the water supply from your main water source been interrupted? How often was there not enough water in the house to wash clothes? How often have you or anyone in your family had to go without a shower because there was not enough water?	11.387
Factor 2	Water access safety distress	How often have you spent time getting water from your home to do household chores (cooking, cooking, laundry, etc.) or other activities? Have you been bothered, worried, or fearful about the safety of the person coming out to get water? How often have you been bothered, worried, or fearful about the safety of the person going out to get water for home?	10.180
Factor 3	Water quality distress	How often did you or someone in your household drink water that tasted bad? Have you been bothered, worried, or afraid to drink or use water? How often were you bothered, worried, or afraid to drink or use water?	10.099
Factor 4	Water quality	Was the quality of water intended for human consumption unacceptable for consumption? Have you noticed dirt or other small floaters in the public water supply? Did you smell or smell strong from the water in the public water supply? Have you noticed that the water was of a different or cloudy color?	9.100
Factor 5	Water access distress	Have you or anyone in your household been bothered, worried, or afraid of not having enough water for all your household needs? How often have you or anyone in your household been bothered, worried, or afraid of not having enough water for all your household needs?	8.787
Factor 6	Social and educational costs	How often did children drop out of school for lack of water (e.g., they did not have water for a bath, to prepare food, to wash clothes for school)? How often have water issues prevented you or anyone in your family from attending social events in your community?	7.912
Factor 7	Physical limitations to water access	How often have physical limitations (because you are elderly, a child, or disabled) prevented you or anyone in your family from getting water? How often have you or anyone in your household been unable to get water where they wanted because they were very sick or weak?	6.816
Factor 8	Water budgeting	How often have you or anyone in your family left to buy other things or make a money-saving payment? How often have you or anyone in your family not had money to buy water?	6.781

from house to well distance, time, means of transport, and functionality of the desalination system. As respondents were eager to share, however, during the dry season (September–December), the time spent in line was much longer, and there are reports of residents needing to stay in line for water all day, whereas others preferred to get water at dawn because the queues were shorter.

Survey data also provided information on the modes of water conveyance (Figure 7). Besides the strained effort to walk long distances with heavy water cans, lack of motorized transport reduced the number of containers one could transport, and thus required more trips and longer wait times at the public tap. These differences among households created tensions among residents: People who do not use a car complained because they could not carry more containers, and lack of transportation increased the time to get water.

Whereas global studies indicate women are major water carriers (Geere and Cortobius 2017), gender roles were reversed in Forquilha. Of those responsible for water conveyance, 74.5 percent were male, 15.2 percent were female, and 6.9 percent reported that the responsibility was shared between men and women. Many complained about this responsibility, as they said it was hard work, because they spent the day working and still needed to get water in the well at night. The age of those responsible for obtaining water from the well was primarily between fifteen

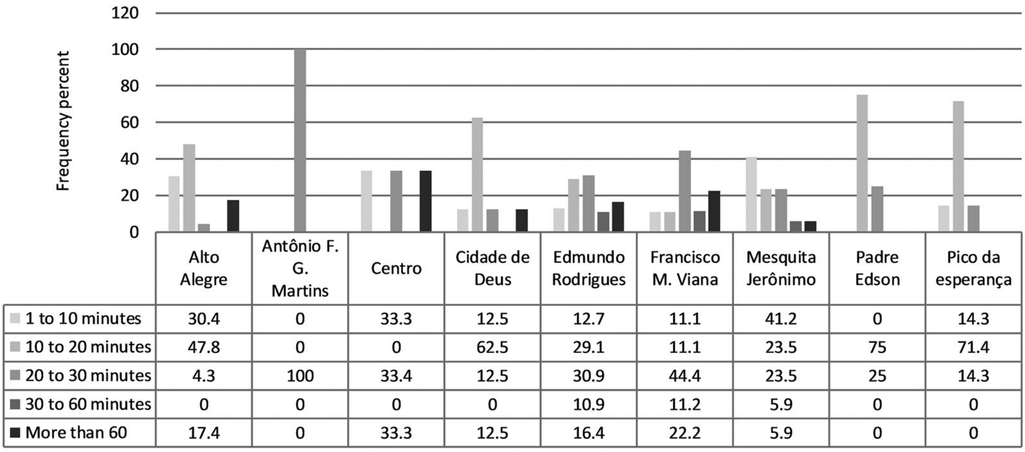


Figure 6 *Average time to collect water (round trip).*

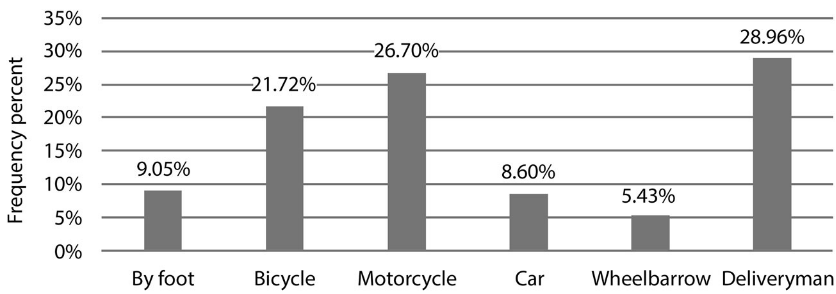


Figure 7 *Water conveyance modes.*

Table 8 *Household water insecurity class for urban center, Forquilha*

		Households	
		N	%
Marginal water insecurity	0.00 ≤ 0.19	84	38.01
Low water insecurity	0.20 ≤ 0.39	82	37.10
Moderate water insecurity	0.40 ≤ 0.63	40	18.10
Severe water insecurity	0.64 ≤ 1	15	6.79
Total		221	100

Note: Analysis of variance result (p value = 0.000); for the level of significance adopted ($p < 0.05$), the null hypothesis is rejected and it is defined that the mean values of the variables differ in at least one of the clusters.

and sixty-five years old (89.0 percent); 2.8 percent of those responsible were under age fifteen, and 4.0 percent were over sixty-five years of age.

Many respondents noted the seriousness of water problems (Table 5, Table 6). Terms used included *stress*, *fear*, *anger*, *anxiety*, and *annoyance*. For some residents, even if the water tasted fine, they expressed concerns about the possible impact of water consumption on health. One respondent stated he was afraid well water would cause kidney stones because of dissolved salts. Others said they were already sick from the water, and another resident reported that the doctor advised him not to drink water from the well (Table 6, Q2). Respondents also reported distress when fetching water. Some residents expressed concern about personal safety for the person fetching water. Residents reported the occurrence of robberies and fights at the wells or on the way to the wells. Women avoided fetching water at night because they felt more vulnerable. Some experienced fear of conflicts and thefts while waiting in line for water.

Measuring Household Water Insecurity

The complex urban water provisioning systems that developed during drought years provide an opportunity to examine the multidimensional and cumulative experience of water crises from the perspective of the household. The HWISI, which is based on a calculation using weighted factors, includes eight components of water insecurity. Table 7 describes the components of each one, the name, and the variance of each factor. The resulting four water insecurity classes reflect increasing severity of household water insecurity. One quarter of respondents experienced moderate to severe levels of household water insecurity (Table 8). Analysis of factor components demonstrates that water insecurity factors were not evenly distributed across the four classes. To better show the domains

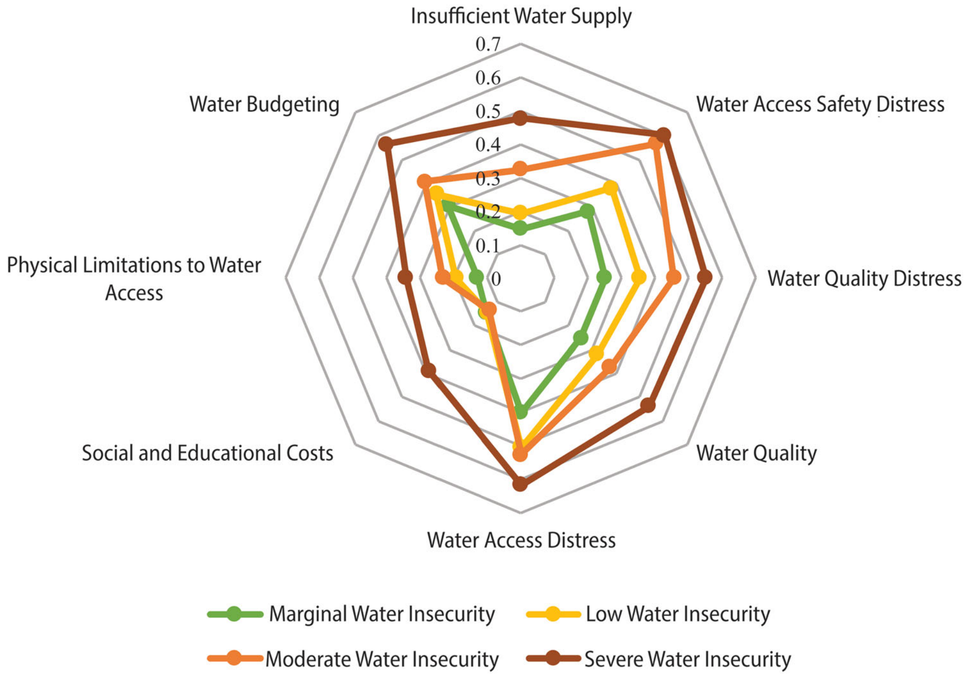


Figure 8 *Distribution of factor means by index class.*

Table 9 *Sociodemographic variable for Household Water Insecurity Index category*

	Marginal water insecurity	Low water insecurity	Moderate water insecurity	Severe water insecurity
Employment (%)				
Formal	14.3	16.7	18.2	0.0
Informal	18.7	26.2	12.1	15.4
Retired/pensioner	25.3	21.4	21.2	15.4
Unemployed	38.5	33.3	48.5	69.2
Gender, head of household (%)				
Male	49.5	54.8	51.5	46.2
Female	40.7	38.1	42.4	46.2
Shared equally	9.9	7.1	6.1	7.7
Household income				
M	1.945	1.605	1.217	766.07
SD	2.233	1.843	1.051	3.507
Household members				
M	3.23	3.68	3.43	3.69
SD	1.552	1.434	1.194	1.494
Members > 18				
M	0.8	1.11	1.0	1.38
SD	0.979	1.105	1.11	1.325
Domicile tenure (%)				
Rent	25.3	28.8	27.3	30.8
Multifamily (shared, no rent)	0.0	2.4	0.0	0.0
Loaned (for payment)	5.5	4.8	0.0	15.4
Owned	63.7	56	72.7	53.8
Owned with mortgage	4.4	4.8	0.0	0.0
Other	1.1	3.6	0.0	0.0

of water insecurity captured in the HWISI and resulting classes, Figure 8 represents the mean factor value in each of the four categories of water insecurity.

Households with the lowest water insecurity (marginal water insecurity), not surprisingly, did not have water supply problems, physical difficulties to access water, social and educational costs of water insecurity, and other experiences of stress, quality, affordability, or restricted access. We identified increasing water problems for low water insecurity households (37 percent). For example, social and education costs and physical limitations are similar to those of the lowest class, but there is notable increase in mean value for water access distress (from 0.282 to 0.379), followed by similar increases

Table 10 *Correlation analysis*

Correlation	Statistics	Insufficient water supply	Water access safety distress	Water quality distress	Water quality	Water access distress	Social/ education costs	Physical limitations to access	Water budgeting	HWISI
No. of children	*R*	0.011	**0.158***	0.022	0.029	0.042	0.108	−0.03	**0.203****	**0.150***
	Significance	0.875	**0.02**	0.748	0.666	0.538	0.112	0.663	**0.002**	**0.026**
No. of household members	*R*	−0.003	**0.157***	−0.003	0.004	0.021	0.109	−0.029	0.127	0.123
	Significance	0.959	**0.02**	0.97	0.952	0.753	0.107	0.671	0.061	0.066
Income (R$ month)	*R*	−0.118	−0.11	−0.043	−0.037	0.061	−0.057	−0.083	**−0.271****	**−0.18****
	Significance	0.084	0.107	0.531	0.586	0.369	0.402	0.224	**0.00**	**0.008**
Water expenditures (total cost)	*R*	0.031	−0.048	−0.085	0.088	−0.043	0.041	−0.015	−0.095	−0.018
	Significance	0.657	0.487	0.219	0.203	0.529	0.555	0.825	0.168	0.792
Affordability (% income for water)	*R*	0.024	−0.062	0.059	−0.007	0.008	0.018	**0.256****	**0.281****	**0.154***
	Significance	0.731	0.368	0.398	0.924	0.907	0.795	**0.00**	**0.00**	**0.025**
Total water sources	*R*	0.049	0.083	−0.058	0.036	0.003	−0.032	**0.196****	0.044	0.117
	Significance	0.467	0.221	0.394	0.596	0.97	0.636	**0.003**	0.514	0.081
Time fetching water (minutes)	*R*	0.042	**0.257****	0.065	−0.087	0.086	**0.146***	0.037	−0.091	**0.173***
	Significance	0.531	**0.00**	0.335	0.198	0.202	**0.03**	0.587	0.18	**0.01**

Notes: Bold values indicate significant correlation. HWISI = Household Water Insecurity Index.
*Correlation is significant at the 0.05 level (two-tailed).
**Correlation is significant at the 0.01 level (two-tailed).

in mean value for the factors of water access safety, water quality, and water affordability.

The third HWISI category, moderate water insecurity (HWISI value of 0.40–0.63), represented 18 percent of the population. Moderate water insecurity is a situation in which families coexist with the lack of water, and there are clear impacts on domestic activities. The factor mean-value differences between low and moderate household water insecurity—that is, the domains of water insecurity that distinguish low from moderate insecurity—are related to insufficient water supply, water quality distress, and water access safety. It is notable that the distress factors related to water access, water affordability, and social and educational costs are similar for low and moderate levels, suggesting that the thresholds for households moving into a more severe category are tied to a specific water insecurity domain.

Our analysis also found that 6.8 percent of the households experienced severe water insecurity (HWISI values 0.64–1). Mean values for severe water insecurity demonstrably increased for all the factors, with the exception of water access safety, which is similar to moderate water insecurity. Therefore, households facing severe water insecurity are experiencing ever increasing challenges across most of the domains of household water insecurity when compared to households experiencing moderate water insecurity. Household characteristics of each group provide further insight into who bears the burden of household water insecurity during times of drought (Table 9).

We also examined the correlations between sociodemographic factors and water insecurity factors. Overall, our analysis identified statistically significant correlations between several key variables (Table 10). Factor 1 (insufficient water supply) negatively correlates with income, which is expected. Those with higher incomes have access to alternative sources available on the private water market. These households have access to motorized transport so less labor is required to convey water. Factor 2 (water access safety distress) is positively correlated with number of household members, number of children, and time to fetch water. Unsurprisingly, Factor 6 (social and educational costs) also correlates with time to fetch water, as survey results revealed how various barriers to water fetching alter household daily activities. Factor 7 (physical limitations to access) positively correlates with total number of water sources and percent of income spent on water. This confirms observations noted during fieldwork suggesting that physical limitations (e.g., disability, age) pushed households to increase vendor-delivered (and thus more expensive) water purchases as their physical disability limited access to public taps. Factor 8 (water budgeting) correlates positively with three sociodemographic variables (number of children, number of household members, and percentage of income spent on water) and it negatively correlates with monthly income. Again, both of these follow expected relationships: households with higher water demands have more water costs and thus are faced with household budget trade-offs, whereas those with higher income do not have those experiences as frequently.

Our final correlation examined the associations with the HWISI score. Our analysis indicates an inverse relationship between income (–0.18, $p = 0.008$) and HWISI score, whereas positive and significant correlations exist between number of children (0.015, $p = 0.026$), percentage of income spent on water (0.154, $p = 0.025$), and time to fetch water (0.173, $p = 0.010$). These are not strong associations, but taken together they indicate that greater water supply needs (more children), higher relative expenditures on water, and time to fetch water increase water insecurity among the most vulnerable.

Discussion

Our study, designed to represent urban residents' water insecurity experience at a 90 percent confidence level, provides insight into a typical small urban center from the perspective of the household. Despite almost 99 percent coverage of residential piped water, drought undermined the viability of urban water systems. We quantified the widespread practice of diversifying water sources as a coping strategy, and also documented the various dimensions of how urban water governance failures unevenly altered everyday activities. Households with motorized transport required less time and effort to fetch water from unmanaged public taps with desalinated groundwater. As our factor analysis and index indicated, greater water supply needs (more children), higher relative expenditures on water, and time required to fetch water increased household water insecurity.

We also reported unexpected results. The predicted food–water insecurity relationship was very weak (Wutich and Brewis 2014; Brewis et al. 2020). Similarly, household cultural and educational trade-offs to secure water were low. Third, expected gendered differences in water fetching were reversed. Men held more responsibility for collect watering. As Wutich (2009) illustrated, however, gendered divisions of water work dissolve during times of drought and crisis. Therefore, future work will have to tease out the gendered division of labor and access to transportation under different, less extreme conditions and how that might shift gender water burdens.

We also document the increasing reliance on unauthorized or informal water vending, which has rather ambiguous outcomes for achieving water for all (Wutich, Beresford, and Carvajal 2016). Our analysis provided quantitative and qualitative data critical to detail the ties between water governance and households' water insecurity via informal water vendors. Municipal public taps and the system's failure to improve water quality produce conditions under which informal water vendors increased the importance of self-provisioning of water. Informal water vending fulfills an immediate need, but as noted by our respondents, vendors also created their own demand. The rise of informal vendors, especially those using the public well, hoarded space in line for public water with many jerry cans and other containers, which increased waiting times. The resulting increase in waiting time perversely increased the demand for water vendor services by vulnerable individuals and households who could not afford that extra effort. Threats of violence, which increased over time, compounded the produced water scarcity to further create barriers to collect public water, and thus increase water expenditures. Unlike larger cities with various options for water provision and bottled water sales—both formal and informal—the urban residents in the small city were highly reliant on a small number of taps that could be captured by a cadre of vendors, who were able to create relative scarcity by effectively privatizing public taps.

Underreported in the literature on drought and water insecurity is the challenge of water quality. As our analysis of survey data indicates, urban water system's failure to manage water quality during drought exacerbated scarcity of drinking water. Our study demonstrated that poor water quality determined how household water managers navigate the urban waterscape, leading to, as the scholarship would anticipate, varying levels of emotional distress. Thus, our analysis also underscores emotional distress and experiences of water quality, which often are left out of the debates over equity, compounding the ever-present material challenge of water access, affordability, reliability, and availability.

Our study also developed novel analytics of household water insecurity that quantify the interacting, copresent, and cumulative experiences of water and hydrosocial relations beyond access. Correlation analysis confirmed expected sociodemographic and water provision associations between each factor and the index, thus offering a validation of this approach. This study demonstrated, with the application of factorial analysis and the development of the HWISI, that regional analyses can refine how these water insecurity dimensions are relational in time and space, attending to the theoretical framework outlined by Jepson, Budds, et al. (2017). Importantly, our analysis of the index subcomponents advances existing household water insecurity scholarship because it demonstrates that although insecurity domains are all copresent, they differ in terms of influence on overall water insecurity experiences. Moreover, this analysis reveals the specific water insecurity domains that push households across water insecurity thresholds. Water quality distress increased equally as households moved into higher categories of insecurity, whereas social and educational costs were equivalent across the HWISI classes except for the most severe, suggesting this is a key threshold of the highest levels of household water insecurity. This finding is important because it illustrates that not all domains equally shape the experience of household water insecurity.

Finally, attention to water insecurity experiences at the household level—particularly in terms of the differential dimensions that influence water insecurity as factors—provides necessary information to develop targeted policy interventions specific to regional characteristics and experiences of household water insecurity. Insecurity differences across the urban center allow us to identify populations where interventions and investment might mitigate the worst impacts of drought and develop resiliency plans for those experiencing the most severe household water insecurity. That is, the index provides policymakers with information to target those threshold domains for intervention to improve household water insecurity experiences. In the case of Forquilha, it is possible to identify households experiencing the most water insecurity. Based on careful analysis of the factors, in times of severe drought, targeting water affordability programs paired with other interventions to address water quality concerns could reduce water insecurity. Better governance of key standpipes could also limit the time required to obtain water and distress for households. For those households experiencing moderate water insecurity, water quality concerns and safety related to water access could also be addressed to alleviate insecurity. Furthermore, water quality requires attention, which seems to be overlooked in current drought management policies. Thus, the HWISI information provides clearer targets to alleviate specific challenges of communities as they face an uncertain climate future.

We also want to acknowledge our study's limitations. Our study is cross-sectional with data collected during the end of a drought; thus, we expect longitudinal data to reveal variations of insecurity over time. Our research does not address variability between seasons or between severe climate events. In addition, the dates of data collection during the rainy season, even in drought, mean that our results are likely to be more conservative; that is, they probably underestimate household water insecurity during the most extreme periods of the drought. Also, this study demonstrated the efficacy of the HWISI as an analytic tool, but we would expect class boundaries of water insecurity to vary.

Conclusion

This article moved forward the discussion on urban water security and equity along three lines of analysis and empirics. First, we addressed the question of water security for whom to examine interactions between urban water governance and the cascading consequences for household water insecurity experiences. By flipping the script from a supply-side to a demand-side analysis, and pairing this with a comprehensive household water insecurity survey that is 90 percent representative of an urban area in northeast Brazil's semiarid region, we were able to robustly describe how households and communities in small cities cope with failing systems under severe strain and, in this case, failed water management. By quantitatively analyzing household-scale water insecurity, we also provided important information on variability across the urban waterscape. This also required that we develop new metrics or quantitative analytical approaches. In this article, we demonstrated the efficacy of the first household water insecurity analysis using the HWISI to compare the specific domains of water insecurity. Analysis of the index subcomponents reveals dominant factors or domains that push households across water insecurity thresholds. Such information provides insight for urban water resilience interventions that are not only effective, but also equitable during times of severe drought for the semiarid region of Brazil. ■

Acknowledgments

We thank Justin Stoler, Christian Brannstrom, and the anonymous reviewers for their support and advice in preparing this article.

Funding

Research for this publication was funded by the National Science Foundation (BCS-1560962, Geography and Spatial Science Program). We also thank the U.S. Fulbright Scholar program (Wendy Jepson, 2016–2017) for its support of our international collaboration.

Note

[1] Based on the factors extracted from the factor analysis, the HWISI was constructed through mathematical calculation: $IA_j = \Sigma_{i=1}^{n} w_i f_{ij}$, where IA_j is an aggregate

index of the j–ith observation; w_i is the weight attributed to the ith factor (w_i is the percentage of variance explained by factors i/percentage of variance explained by all factors); f_{ij} is the factorial score of the ith component for the ith observation; $i = 1, \ldots, p$ (principal components) and $j = 1, \ldots, n$ (observations). Finally, the index was standardized by a method expressed as follows: $I_{pji} = I_{ji} - I_{jr}/I_{jm} - I_{jr}$, where I_{pji} is the standardized value of indicator j in the ith observation; I_{ji} = is the indicator value j on the ith observation; I_{jr} is the value of indicator j on worst situation observation; and I_{jm} is the value of indicator j on best situation observation.

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