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Research Paper

Coping with water insecurity despite access and abundance in the urban Amazon

Steven Jay Rhue [a,*], Barbara A. Piperata [a] and Uriel Lopes[b]

[a] Department of Anthropology, The Ohio State University, Columbus, OH, USA
[b] Ciências Sociais, Universidade Federal do Pará, Belém, Pará, Brazil
*Corresponding author. E-mail: rhue.3@osu.edu

SJR, 0000-0002-0762-9093; BAP, 0000-0002-7392-4517

ABSTRACT

Research on household water insecurity continues to overemphasize water scarcity and rural contexts, resulting in a poorer understanding of water insecurity in urban, water-abundant settings. At the same time, while the dimensions of water insecurity include availability, access, utilization and stability, current instruments focus on access to water, thus, inadequately explore people's experiences utilizing available water. This study aimed to characterize and explore the impacts of household water insecurity on residents of the city of Belém, Pará, Brazil, where water is available and access to piped municipal water is common, but its provision and quality vary. We applied the Household Water Insecurity Experiences Scale (HWISE) to evaluate water insecurity in 188 households (110 LSES; 78 HSES). In a subset of 47 households, we complemented the HWISE with a novel instrument, developed via participant observation, that assessed all points of water access and use within the home. Per HWISE, 28% of households were water insecure, with a higher proportion of water insecurity occurring in LSES households. Data collected via our complementary instrument indicate that HWISE underestimated water insecurity in our sample, as 87% of the subset households reported issues affecting their utilization of water regardless of household water insecurity status.

Key words: infrastructure, socio-economic status, water utilization

HIGHLIGHTS

- Standardized measures of household water security may not capture the full scope of household water problems, which include intermittency and poor quality, in urban, water-abundant contexts.
- Income does not fully buffer against household-level water insecurity.
- Coping strategies do not guarantee access to safe and sufficient water.

INTRODUCTION

Research on household water insecurity continues to emphasize water scarce and rural contexts, leaving us with an underdeveloped appreciation of water security in urban, water-abundant settings (Romero-Lankao & Gnatz 2016; Maskey *et al.* 2023). This is problematic, as over 50% of the global population lives in cities (The World Bank 2023), the majority of whom lack adequate water and sanitation (United Nations Water 2024). Some 66 million urban inhabitants lack safely managed water for their everyday needs, while 168 million are without sanitation (WHO/UNICEF 2024), placing them at risk of disease and emotional distress (Adams *et al.* 2020). These numbers are only expected to grow over the next 25 years, as the urban population is projected to more than double by 2050 (The World Bank 2023); this is the result of rapid, often informal urbanization which outpaces governments' ability to provide water and sanitation for all (United Nations 2024).

The study of an urban context is distinct within the field of water insecurity, as urban water is uniquely shaped by high population density, multiple scales of formal governance, and a dependence on vast quantities of water (Hoekstra *et al.* 2018). Inherently, urban centers are dense concentrations of people organized around finite resources and infrastructure (Weeks 2010). This is especially true of water, as it is fundamental to socio-economic growth and development (The World Bank 2023). The provision of water is then contingent on a municipality's capacity to secure, treat, and distribute it; processes governed by an increasingly fluid and complex constellation of agencies at the local, regional, and national level

(Truelove 2019). Additionally, the amount of water necessary to sustain an urban population is substantial, as the world's largest cities depend on more than 600 billion liters of water a day (McDonald *et al.* 2014).

Although evaluated at multiple scales (i.e., global, regional, and local), water insecurity is often studied at the household level. Our current understanding of household water security is primarily informed by research that focuses on the domains of availability and access (Young *et al.* 2021), which examines and characterizes where and how households obtain water (Nounkeu & Dharod 2019). Fewer studies address household utilization (i.e., the use and distribution of water within the home). Water may be available and accessible, but intermittent (Young *et al.* 2021), leading to disruptions that don't prevent water-related activities, but significantly alter daily routines (Thomson *et al.* 2024). Further, accessible water may be of variable or unknown quality, leaving households to rely on the water they have, even if concerns over its use linger (Badhwa *et al.* 2022).

At the same time, while water scarcity is often perceived as the primary cause of urban water insecurity (Hoekstra *et al.* 2018), an abundance of water does not guarantee water security (Praskievicz 2019). Insufficient investment in distribution networks may leave water unavailable to population centers (Arnell 1999) and poor management can leave urban water supplies vulnerable to the impacts of climate change (Vörösmarty *et al.* 2000). Even in cities where most residents enjoy access to piped water, water insecurity may persist due to inequitable distribution and management of water-sanitation infrastructure (Grasham *et al.* 2022). These deficits are often more pronounced in low-income neighborhoods and informal settlements (World Health Organization 2024), where there is little incentive to maintain or restore water services due to socio-economic exclusion and discrimination (Aguilar & López 2009; Sarkar 2022).

The goal of this study is to further our understanding of urban household water security in a water-abundant context. The Amazon region of Brazil represents an ideal place to conduct this work. The Amazon accounts for nearly 20% of the world's freshwater, providing drinking water for millions of South Americans (Agência Nacional de Águas 2012). While mention of the Amazon conjures up images of a sparsely populated, densely forested region, the reality is that >70% of the region's residents reside in urban areas (Costa & Brondizio 2011). Despite the abundance of water, residents of Amazonian cities face numerous issues as over-taxed infrastructure, resulting from rapid and unplanned urban expansion, often means that available water is unequally accessible (Soares 2022). In fact, studies show that the region's largest capitals, Manaus and Belém, lack adequate potable water and sanitation infrastructure (Prez 2000; Mansur *et al.* 2018).

Our research is guided by two specific aims. First, using a well-established experiential measure, we sought to understand household water experiences in the urban and water-rich city of Belém, Brazil. We include both high socio-economic status (HSES) and low socio-economic status (LSES) households, as municipal water infrastructure is shared, and prior work (Shah *et al.* 2023) has demonstrated that households in densely populated urban areas remain vulnerable to water insecurity across socio-economic status. Second, using a novel instrument developed from ethnographic observations, we aimed to understand the ways water insecurity influences household water utilization and thus its impact on people's daily lives.

METHODS

Field site

Belém is the capital of the Brazilian state of Pará (Figure 1). The city is bordered by the large bays and rivers that comprise the mouth of the Amazon River and receives ~3,000 mm of annual rainfall (Pegado *et al.* 2012). A legacy of rapid and often informal urbanization has resulted in disparities in income, housing, as well as water and sanitation infrastructure. Just 36% of the city's 1.3 million people are formally employed (IBGE 2022), and over half (~57%) live in *baixadas,* low-lying areas recognized for their sub-standard living conditions and risk of flooding due to poor drainage. Water is provided by the Sanitation Company of Pará (Companhia de Saneamento do Pará – COSANPA) and sourced from a network of lakes, estuaries, and subterranean wells. However, just 65% of the city's population has access to the municipal water system (Unidade Coordenadaora do Programa Belém 2020) with household connection rates varying by neighborhood (<20 to >80%) (Mansur *et al.* 2018).

Recruitment and data collection

We collected data for this research as part of a longitudinal study aimed at understanding how household ecology, including water and food security, influences infant development and health in the first 2 years of life. With the assistance of doctors and nurses at local public and private hospitals, public health clinics, as well as via advertisements on social media, we

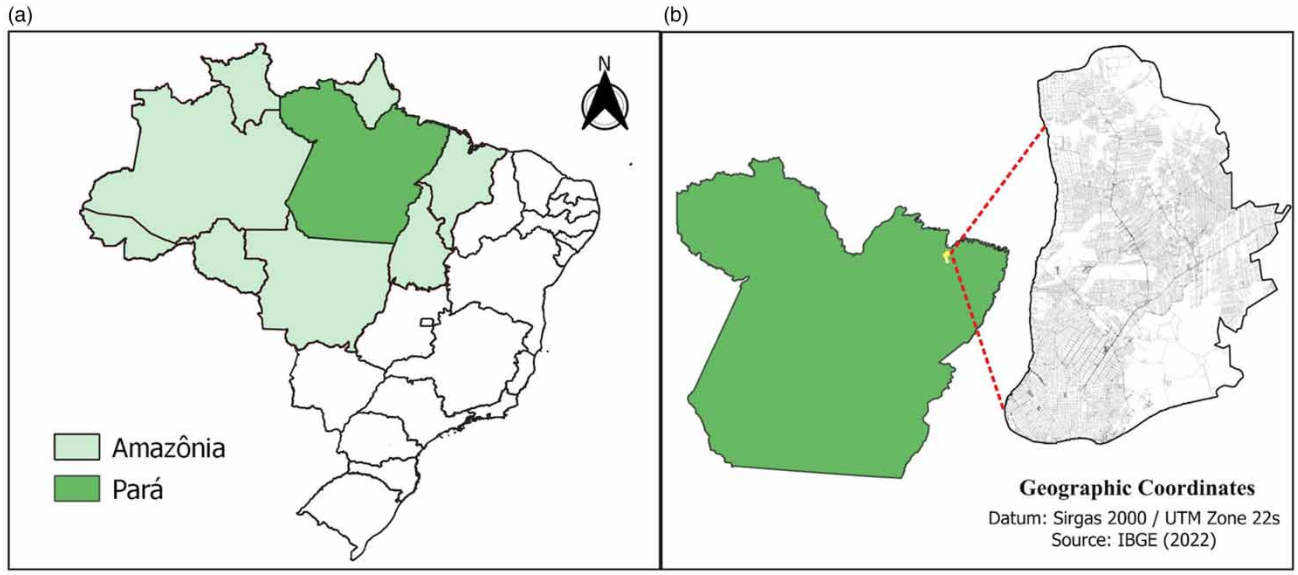

Figure 1 | Map showing the (a) location of the Brazilian State of Pará and (b) location of the municipal area of the capital city of Belém.

recruited 190 households. Of these 190 households, we had complete data for 188. All data were collected during home visits, and the female head of household was the principal respondent.

Aim 1

To characterize household socio-economic conditions, we administered a survey instrument to the female household head that inquired about her age, partner status, educational attainment, and employment (formal or informal). We also collected data on household demographics, location (longitude and latitude), water infrastructure, and monthly income. To determine household economic status, we used the criterion established by the Brazilian government to assess eligibility for social support programs, where LSES is defined as total monthly income less than 3× the minimum wage (Caixa Econômica Federal 2022). Those exceeding this value were classified as HSES.

To assess household water security, we used the Household Water InSecurity Experience's (HWISE) Scale. The HWISE is a 12-item scale validated for use in low-middle-income countries that assesses 12 domains of water security over the previous 4-week period; worry, interruption, washing clothes, plans, food, handwashing, body washing, drinking water, anger, sleeping, no water, and shame (Young *et al.* 2019). Responses to each item include never (0 times), rarely (1–2 times), sometimes (3–10 times), often (11–20 times), and always (>20 times). Never is scored a 0, rarely as 1, sometimes as 2, and often and always are both scored as 3. The sum of the 12 items results in a total score of 0–36. A score of 12 or more indicates household water insecurity (Young *et al.* 2019). We also asked participants if they experienced interruptions to water service and, if so, whether they were announced or unannounced. Responses to this last question are treated separately and not used in the calculation of the HWISE score.

Aim 2

Drawing on our observations and conversations, we developed the household water infrastructure and utilization (HWIU) instrument, which focused on household water infrastructure and utilization, to complement data from the HWISE. The instrument documents all water access points (WAP) (e.g., sinks, showers, spigots, etc.) located inside and immediately outside the home. Using a standard set of questions, we inquired about (a) what activities the WAP is used for; (b) if there are any problems with the water from that WAP; (c) the frequency with which any identified problem(s) occurred; and (d) the ultimate source of water for that WAP (e.g., municipal, purchased, well, rain, etc.). We also asked about coping strategies and the perceived quality of water for consumption and daily tasks. Photographs were used to further document problems and coping strategies. We administered the HWIU in a sub-sample of $n = 47$ LSES households, where issues with household water were most pronounced.

Ethics

We received institutional review board approval from the Comissão Nacional de Ética em Pesquisa (CONEP) (número de parecer 4.043.620), the Brazilian federal agency that reviews international research with human subjects and The Ohio State University (2020B0014). At the time of recruitment, we provided an overall description of the project and shared a copy of the informed consent form with the potential participant. We then reviewed the form verbally with the potential participant, stopping to answer questions or clarify points at the end of each section. If the participant agreed to take part in the study, we asked her to sign two copies, one of which she kept. We stored the other copy in a locked cabinet at the Federal University of Pará.

Data analysis

We used descriptive statistics to summarize data on participants and their households. To address aim 1, we summed the responses to the 12 HWISE items (0–36). Following previous studies (HWISE-RCN 2019), a score of 12 or higher was used to define a household as water insecure. We used the Mann–Whitney U test to identify differences in HWISE scores between LSES and HSES households and the Chi-Square test of independence to identify differences in water security status by SES (i.e., $p < 0.05$). To address aim 2, we used descriptive statistics to summarize findings from the HWIU instrument. To understand how water problems impacted people's everyday lives and the strategies they used to cope with them, we reviewed and summarized data collected via the HWIU survey and in fieldnotes. Data analyses were conducted in Microsoft Excel and SPSS (IBM ver 29). We used GPS coordinates to map the spatial distribution of the households. Spatial analyses were conducted in QGIS (ver 3.28.15 - firenze) using data made available by the Minerals Research Resource Company (CPRM), the Brazilian Institute of Geography and Statistics (IBGE) and Google Satellite.

RESULTS

Participant and household characteristics

Characteristics of the study participants and their households are reported in Tables 1 and 2. The average age of the female respondents was 30 ± 6.4 years and 90% were married or living with a partner. The average household size was 4.5 ± 1.4 and

Table 1 | Characteristics of study participants

	All $n = 188$ **Mean (SD)**	**LSES** $n = 110$ **Mean (SD)**	**HSES** $n = 78$ **Mean (SD)**
Age (years)	30 (6.4)	28 (6.6)	33 (4.9)
	n (%)	n (%)	n (%)
Partner status			
Married	69 (37)	26 (23)	43 (55)
Stable union	100 (53)	69 (63)	31 (40)
Single	19 (10)	15 (14)	4 (5)
Education			
College coursework/degree	73 (39)	12 (11)	61 (78)
High school (grades 10–12)	90 (48)	74 (67)	16 (21)
Primary II (grades 6–9)	18 (9)	17 (15)	1 (1)
Primary I (grades 1–5)	5 (3)	5 (5)	0 (0)
No formal education	2 (1)	2 (2)	0 (0)
Employment			
Employed	106 (56)	40 (36)	66 (85)
Formal	76 (40)	26 (24)	50 (64)
Informal	30 (16)	14 (12)	16 (21)
Unemployed	82 (44)	70 (64)	12 (15)

Table 2 | Household characteristics

	All *n* = 188 Mean (SD)	LSES *n* = 110 Mean (SD)	HSES *n* = 78 Mean (SD)
Household size	4.5 (1.7)	4.6 (1.4)	4.3 (2.2)
Household income (R$)[a]	6,410 (8,463)	1,605 (745)	13,186 (9,725)
Household drinking water expenses (R$ last month)	63 (68)	56 (52)	73 (84)
	n (%)	*n* (%)	*n* (%)
Household location			
Baixada zone	129 (69)	104 (95)	25 (32)
Elevated zone	59 (31)	6 (5)	53 (68)
Street adjacent to home			
Paved	167 (89)	91 (83)	76 (97)
Unpaved	21 (11)	19 (17)	2 (3)
Floor construction			
Ceramic tile	156 (83)	87 (79)	69 (89)
Finished concrete	18 (10)	11 (10)	7 (9)
Bare concrete	10 (5)	9 (8)	1 (1)
Wood	4 (2)	3 (3)	1 (1)
Wall construction			
Plastered brick	167 (90)	92 (83)	75 (96)
Bare brick	9 (5)	8 (7)	1 (1)
Wood	4 (2)	4 (4)	0 (0)
Concrete	6 (2)	4 (4)	2 (3)
Mixed materials	2 (1)	2 (2)	0 (0)
Household water source			
Municipal	151 (80)	103 (94)	48 (62)
Artesian well	33 (17)	4 (3)	29 (37)
Purchased	1 (1)	1 (1)	0 (0)
Other[b]	3 (2)	2 (2)	1 (1)
Drinking water source			
Purchased	117 (62)	67 (61)	50 (64)
Municipal	36 (19)	27 (24)	8 (10)
Filtered municipal	29 (15)	13 (11)	16 (21)
Artesian well	7 (4)	3 (3)	4 (5)
Sanitation			
Indoor bathroom	178 (95)	101 (92)	77 (99)
Outhouse/other	10 (5)	9 (8)	1(1)

[a]$R1 to $US0.18.
[b]River water, communal well, unsure.

the reported average monthly income was R$ 6,410 (~$1,200 USD) but ranged between R$ 200 and R$ 40,000 (~$36–7,300 USD). Almost all LSES households were in *baixada* zones. The majority (68%) of HSES households were in more elevated and developed parts of the city. While 80% of households relied on municipal water as their primary water source, just 19% reported using municipal water for drinking. Most (62%) purchased drinking water, spending, on average, R$ 64 (~$12) per month.

Household water security: LSES vs HSES

Median HWISE score for the $n = 188$ households was 4.0 and ranged between 0 and 36 (Table 3). HWISE scores were significantly higher in LSES households ($Md = 9$, $n = 110$) compared to HSES ($Md = 0$, $n = 78$), $U = 2003$, $p < 0.001$). Using the standard cut-off for defining water insecurity (score ≥12), 28% of households were classified as water insecure. Similarly, the rate of water insecurity was higher in LSES (38%) compared to HSES (14%) households ($X^2 = 13.4$, $p < 0.001$).

Sixty-seven percent of households reported interruptions to water service and, 47% of the time, they were unannounced. Interruptions were more common in LSES households; 75% of LSES households reported interruptions compared to 31% of HSES households. Sixty-one percent of LSES households reported being unable to wash clothes, while 57% reported having to change plans. Although participants reported that issues with household water affected handwashing, eating, and bathing, these experiences were less frequent. In terms of potable (usable or drinkable) water, 52% of LSES households reported having none in the home at some point over the previous 4 weeks compared to 14% of HSES households.

Anger was the most often reported emotional experience. Sixty percent of participants from LSES households reported feeling angry about their water situation, while just 23% of HSES households reported feelings of anger. Fifty-two percent of LSES households reported worry. HSES households reported worrying less frequently (22%). While feelings of shame were less common, 41% of LSES households reported experiencing shame due to their water situation. Shame was reported by only 14% of HSES households.

Ethnographic insights from the HWIU instrument

Application of the HWIU instrument in $n = 47$ LSES households located in the *baixadas* allowed us to further investigate intermittency, perceptions of quality, and coping strategies. Of the $n = 47$ households, 31 were water secure and 16 water insecure (Table 4; Figure 2). In total, we documented 247 individual WAPs. On average, households had five WAPs within or immediately outside their home; however, this ranged from one to 13.

The most common WAPs were faucets, showers, and purchased 20 L bottles of water, colloquially referred to as *garrafões*. Faucets were the most versatile WAP, and were either paired with a basin (e.g., plastic, porcelain, metal) and used as a sink for preparing meals, hygiene (bathing, washing hands, brushing teeth) or as a connection for appliances and hoses used for cleaning. *Garrafões* were most often purchased from street vendors, open-air markets, and/or grocery stores. Ranging in price between $US 1.50 and 3.35 and marketed as mineral water, *garrafões* were used almost exclusively for drinking. Just over 30% of households had a *caixa d'agua*. Typically located on rooftops or mounted on scaffolding, these large (≥200 L) plastic containers store and supply water to multiple WAPs within the home.

The majority (87%) of the 47 households reported a problem with at least one WAP. Interruptions to water service (57%) were the most frequently reported problem (Table 4). In all cases, interruptions were intermittent and generally of short duration (~3–24 h). Discussions with residents revealed that interruptions to water service were often the result of maintenance by COSANPA or damage to municipal water lines. Other common problems were low pressure (57%), the presence of sediment (37%), a yellow discoloration (30%), and foul smell (13%) (Table 4). These problems tended to co-occur, often following interruptions to water service, with some households reporting four or more occurring simultaneously (Figure 2).

Impacts and coping strategies

As a single WAP was used to perform multiple tasks, problems with one could significantly impact daily routines. For example, interruptions to water service and/or low pressure at a faucet could disrupt the cleaning of dishes and clothing, leaving them to accumulate until service/pressure was restored (Figure 3(a)). Discoloration, sediment, and/or foul odor meant that accessible water could not be used for bathing, cooking, or drinking. As the municipal system was the ultimate source of water for most WAPs in the home, problems with this water disrupted almost all household activities (Figure 4).

Under these circumstances, participants reported forgoing water-intense routines, especially bathing. Being unable to bathe meant adults and children were unable to cool down during the heat of the day, which is especially relevant in Belém where the average daytime temperature is 90° F (32° C). As a result, participants reported fatigue and being unable to sleep at night. Heat-related rashes were one of the most reported child health concerns. Interruptions could also interfere with meal preparation, forcing people to purchase premade items from street vendors, delay or even skip a meal.

In anticipation of interruptions to water service, participants reported filling 5–40 L containers (Figure 5(a)). Stored water was used primarily for bathing, washing clothes and dishes, and cleaning the home. Having a *caixa d'água* (Figure 5(b)), which are expensive (~$300–500 USD), proved particularly useful as households could ration that stored water for 3–4

Table 3 | Household water insecurity experiences scale (HWISE)

		All $n = 188$ n (%)	LSES $n = 110$ n (%)	HSES $n = 78$ n (%)	Statistical Test
HWISE (median)		4	9	0	[a]$U = 2003$
HWISE (range)		0–36	0–36	0–27	$p < 0.001$
Water security status					
Water secure	HWISE <12	135 (72)	68 (62)	67 (86)	[b]$X^2 = 13.4$
Water insecure	HWISE ≥ 12	53 (28)	42 (38)	11 (14)	$p < 0.001$
HWISE Item: In the last 4 weeks…	Frequency of occurrence				
Have you or someone in your households been worried that you do not have enough water for all of your needs?	Never (0)	114 (61)	53 (48)	61 (79)	
	Rarely (1–2)	22 (12)	17 (16)	5 (6)	
	Sometimes (3–10)	25 (13)	20 (18)	5 (6)	
	Often/Always (11+)	27 (14)	20 (18)	7 (9)	
Has the water supply in your home been interrupted or limited?	Never (0)	81 (43)	27 (25)	54 (69)	
	Rarely (1–2)	32 (17)	24 (22)	8 (10)	
	Sometimes (3–10)	28 (15)	19 (17)	9 (12)	
	Often/Always (11+)	47 (25)	40 (36)	7 (9)	
Has there not been enough water to wash clothes?	Never (0)	100 (53)	43 (39)	57 (73)	
	Rarely (1–2)	36 (19)	28 (26)	8 (10)	
	Sometimes (3–10)	26 (14)	21 (19)	5 (7)	
	Often/Always (11+)	26 (14)	18 (16)	8 (10)	
Have you or someone in your household had to change your plans because of problems related to water?	Never (0)	109 (58)	47 (43)	62 (79)	
	Rarely (1–2)	31 (16)	26 (24)	5 (6)	
	Sometimes (3–10)	24 (13)	20 (18)	4 (5)	
	Often/Always (11+)	24 (13)	17 (15)	7 (9)	
Have you or someone in your household changed what you were going to eat because of problems related to water?	Never (0)	132 (70)	64 (58)	68 (87)	
	Rarely (1–2)	24 (13)	19 (17)	5 (6)	
	Sometimes (3–10)	17 (9)	15 (14)	2 (3)	
	Often/Always (11+)	15 (8)	12 (11)	3 (4)	
Have you or someone in your household had to go without washing your hands after dirty activities?	Never (0)	142 (76)	72 (65)	70 (90)	
	Rarely (1–2)	22 (12)	18 (17)	4 (5)	
	Sometimes (3–10)	15 (8)	12 (11)	3 (4)	
	Often/Always (11+)	9 (4)	8 (7)	1 (1)	
Have you or someone in your household had to go without bathing because of problems related to water?	Never (0)	129 (69)	65 (59)	64 (82)	
	Rarely (1–2)	28 (15)	22 (20)	6 (8)	
	Sometimes (3–10)	17 (9)	13 (12)	4 (5)	
	Often/Always (11+)	14 (7)	10 (9)	4 (5)	
Was there not enough water for you or someone in your household to drink as you would like?	Never (0)	157 (83)	81 (74)	76 (97)	
	Rarely (1–2)	20 (11)	18 (16)	2 (3)	
	Sometimes (3–10)	9 (5)	9 (8)	0 (0)	
	Often/Always (11+)	2 (1)	2 (2)	0 (0)	
Have you or someone in your household felt angry about your water situation?	Never (0)	104 (55)	44 (40)	60 (77)	
	Rarely (1–2)	20 (11)	14 (13)	6 (8)	
	Sometimes (3–10)	20 (11)	17 (15)	3 (4)	
	Often/Always (11+)	44 (23)	35 (32)	9 (11)	
Have you or someone in your household gone to bed thirsty?	Never (0)	169 (90)	92 (84)	77 (99)	
	Rarely (1–2)	11 (6)	10 (9)	1 (1)	
	Sometimes (3–10)	6 (3)	6 (5)	0 (0)	
	Often/Always (11+)	2 (1)	2 (2)	0 (0)	

(*Continued.*)

Table 3 | Continued

		All $n=188$ n (%)	LSES $n=110$ n (%)	HSES $n=78$ n (%)	Statistical Test
Has there not been potable (drinkable or usable) water in your home?	Never (0)	120 (64)	53 (48)	67 (86)	
	Rarely (1–2)	29 (15)	23 (21)	6 (8)	
	Sometimes (3–10)	21 (11)	18 (16)	3 (4)	
	Often/Always (11+)	18 (10)	16 (15)	2 (2)	
Have you or someone in your household felt shame because of problems related to your water?	Never (0)	132 (70)	65 (59)	67 (86)	
	Rarely (1–2)	22 (12)	19 (17)	3 (4)	
	Sometimes (3–10)	14 (7)	11 (10)	3 (4)	
	Often/Always (11+)	20 (11)	15 (14)	5 (6)	
If your water was interrupted or limited, were these episodes expected or unexpected?	Expected	97 (52)	61 (55)	28 (36)	
	Unexpected	89 (47)	65 (59)	24 (31)	
	No response	2 (1)	1 (1)	1 (1)	

[a] $r = 0.5$ (medium effect size).
[b] Cramer's $V = 0.3$ (medium effect size).

days. A *caixa d'água* also mitigated low pressure, as the gravity-fed water ensured that WAPs on second and third stories remained usable. However, power outages and failure of electrical pumps used to fill these tanks could leave households with insufficient water during service disruptions (Figure 3(b)).

To cope with sediment, discoloration and foul odor, residents often ran faucets for extended periods of time (~30–45 min). This was only viable as few of the 47 households (23%) were receiving a water bill due to delays in the installation of municipal water meters. Another strategy was to use filters. The quality ranged from store-bought filters capable of removing the smallest of particles (Figure 5(d)), to more porous, makeshift cloth/mesh filters (Figure 5(c) and 5(e)). Water passed through a store-bought filter was considered safe for drinking and cooking. While water passed through cloth/mesh filters was considered 'cleaner,' it was reserved for cleaning.

As confidence in the quality of municipal water was low (Table 4), participants reported adding chlorine to household water. However, as most felt this water was unsafe for adults (79%) and children (87%) to drink, the most common strategy used to ensure there was drinkable water in the home was to purchase 20 L *garrafões*. Due to the price, this water was reserved for drinking, although some households reported using it for cooking and basic hygiene during extended interruptions. Importantly, 55% of participants expressed doubt about the safety of purchased water for drinking.

A critical issue affecting water in the *baixadas* was the connection to the municipal system. To access municipal water, households had to contact COSANPA and request a formal connection. This was an expensive (~$107 USD), bureaucratically complicated process that could take upwards of 4–6 months. Therefore, some reported hiring an independent contractor who would do the work faster and cheaper. These unofficial connections further strained the already overburdened water system, and when done incorrectly, reduced water pressure or lead to line breaks. Unable to secure a connection, some households shared water lines with neighbors. This required coordination as only one household could be connected to the municipal system at a time. The household with the 'primary connection' had greater control over the water and could cut the flow to the other home at their discretion.

DISCUSSION

Household water insecurity in Belém, Pará, Brazil

As expected, rates of water insecurity were higher among LSES than HSES households. LSES households more frequently contended with issues related to hygiene (e.g., bathing, washing hands, washing clothes), disruptions to daily routines (e.g., changing plans, changing what was eaten), as well as emotional distress (e.g., worry, anger, and shame). Insufficient water for basic hygiene suggests LSES households are at greater risk of water-related illness and preventable disease (Adams *et al.* 2020). The need to alter plans, including meals, due to poor access to and/or quality of water indicates that LSES households experienced greater disruption to daily life; potentially impacting household income, dietary quality and diversity, and engagement in social activities (Cooper-Vince *et al.* 2017; Frongillo 2023). As LSES participants also reported

Table 4 | WAPs in the sub-sample of $n = 47$ LSES households

	All $n = 47$ Mean (SD)	HWISE <12 Secure $n = 31$ Mean (SD)	HWISE ≥ 12 Insecure $n = 16$ Mean (SD)
HWISE score	10 (8.5)	4 (4.1)	20 (4.1)
Number of WAPs	5 (2.3)	5 (2.5)	5 (1.8)
	n (%)	*n* (%)	*n* (%)
WAPs			
Faucet	47 (100)	31 (100)	16 (100)
Shower	40 (85)	27 (87)	13 (81)
Purchased water (20 L)	24 (51)	14 (45)	10 (63)
Caixa d'agua	16 (34)	11 (35)	5 (31)
Problem with WAP?			
Yes	41 (87)	27 (87)	14 (88)
No	6 (13)	4 (13)	2 (12)
Problems type			
Interruptions	26 (57)	14 (45)	12 (75)
Low pressure	23 (50)	16 (52)	7 (44)
Sediment	17 (37)	11 (45)	6 (38)
Discoloration	14 (30)	10 (32)	4 (25)
Foul odor	6 (13)	4 (13)	2 (13)
Leaks	1 (2)	0 (0)	1 (6)
Is the tap water in your home safe for adults to drink?			
Yes	4 (8)	3 (10)	1 (6)
No	37 (79)	24 (77)	13 (81)
No response	6 (13)	4 (13)	2 (13)
Is the tap water in your home safe for children to drink?			
Yes	0 (0)	0 (0)	0 (0)
No	41 (87)	27 (87)	14 (87)
No response	6 (13)	4 (13)	2 (13)
Is the tap water in your home safe for cooking?			
Yes	20 (42)	17 (55)	3 (18)
No	21 (45)	10 (32)	11 (69)
No response	6 (13)	4 (13)	2 (13)
Is the mineral water sold in Belém safe for adults to drink?			
Yes	26 (55)	16 (52)	10 (62)
No	15 (32)	11 (35)	4 (25)
No response	6 (13)	4 (13)	2 (13)
Is the mineral water sold in Belém safe for children to drink?			
Yes	26 (55)	16 (52)	10 (62)
No	15 (32)	11 (35)	4 (25)
No response	6 (13)	4 (13)	2 (13)
Do you store rainwater for laundry, cleaning, or other daily activities so as to not depend on municipal water?			

(*Continued.*)

Table 4 | Continued

	All $n = 47$ Mean (SD)	HWISE <12 Secure $n = 31$ Mean (SD)	HWISE ≥ 12 Insecure $n = 16$ Mean (SD)
Yes	2 (4)	1 (3)	1 (6)
No	39 (83)	26 (84)	13 (81)
No response	6 (13)	4 (13)	2 (14)

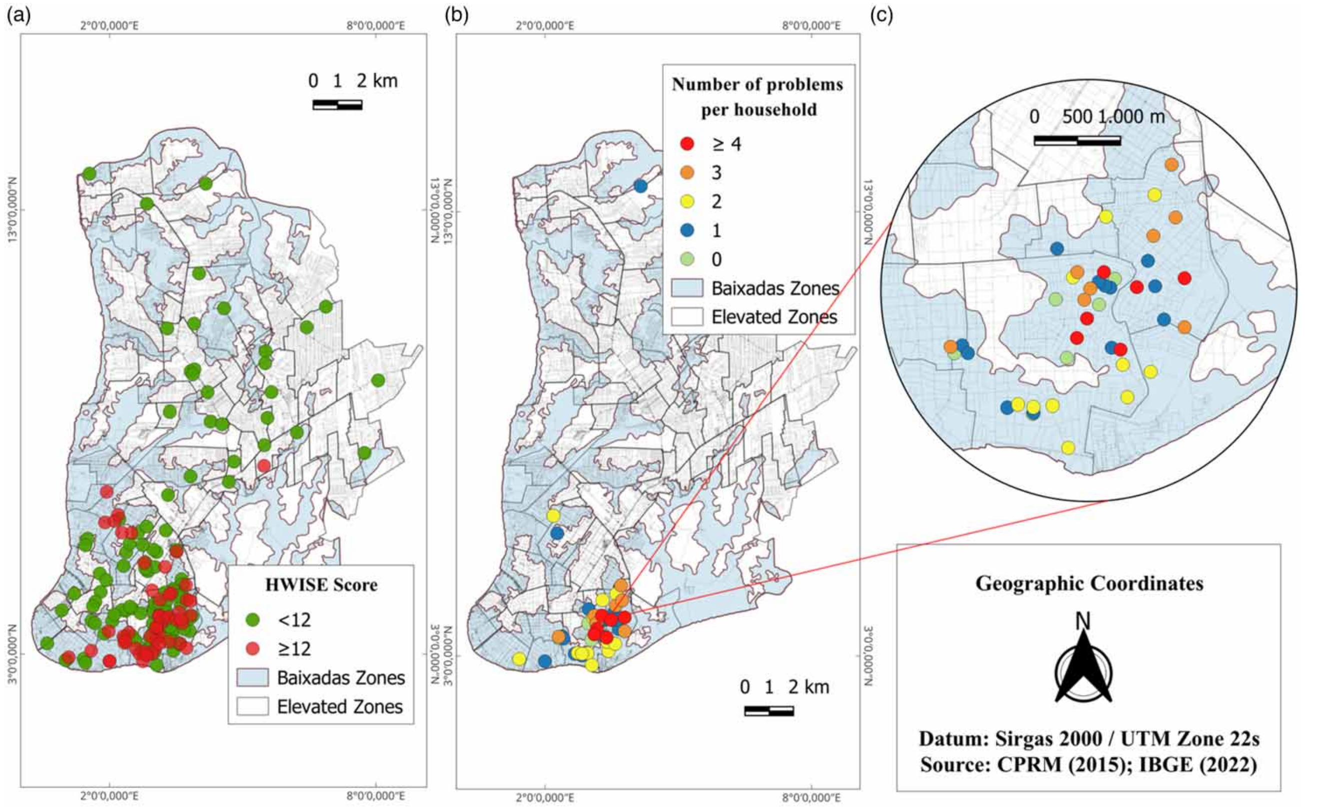

Figure 2 | (a) Household water security based on the HWISE scale cut-offs (<12 = water secure; ≥12 = water insecure). (b) Number of reported problems with household water in the sub-sample of $n = 47$. (c) Map showing the concentration of household water problems in *baixada* zones.

higher rates of water-related emotional distress, they are also at greater risk of experiencing depression and anxiety (Brewis *et al.* 2019).

As municipal infrastructure is shared across elevated and *baixada* zones, HSES, like LSES households are vulnerable to experiencing interrupted or limited water service. Water lines often break due to age, erosion, and clandestine connections, allowing water to escape or obstructions to impede flow (Unidade Coordenadaora do Programa Belém 2020). The municipality of Belém recently launched a project to address water issues in the city, which includes replacing water lines and formally connecting households to the municipal water supply. Unfortunately, while these projects are underway, service interruptions in both HSES and LSES homes remain common. Enforcing formal connections to municipal water may place additional financial strain on LSES households who benefit from informal, unmetered connections.

Subsidies that off-set the costs of formal connection to the municipal water system are attractive, as they offer a monetary incentive in exchange for a formal connection, which generally improves pressure and flow within a water network (Acey *et al.* 2019). However, recent studies report that poor households rarely receive the full financial benefit of subsidies,

Figure 3 | (a) Unwashed laundry sitting in a sink due to inadequate water. (b) A broken water pump used to fill household *caixa d'agua*.

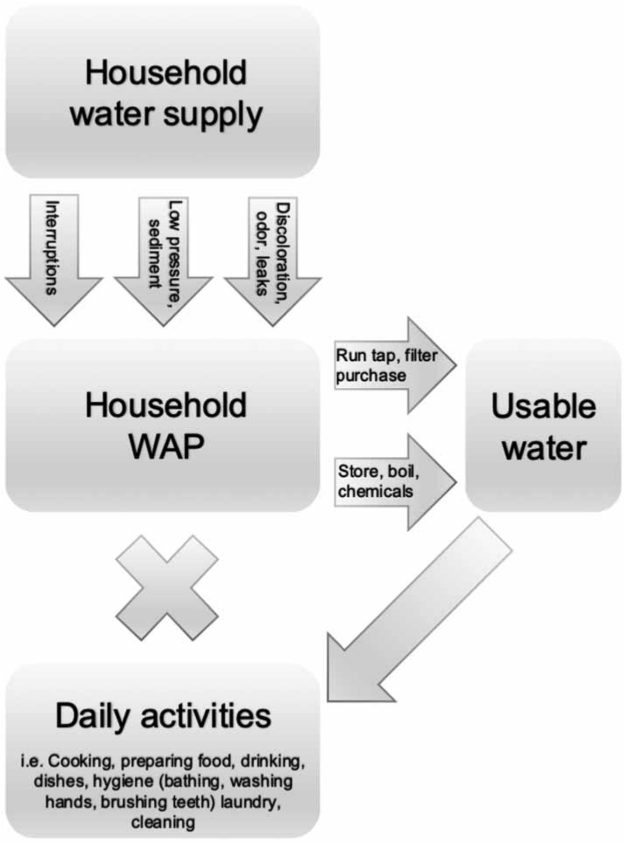

Figure 4 | Problems with water experienced by households and coping strategies.

Figure 5 | (a) Small container used to store bathing water. (b) 1,000 L *caixa d'agua*. (c) Homemade cloth filter attached to faucet. (d) Store-bought water filter on kitchen faucet. (e) Mesh handheld filter(s) used to capture larger particles.

as they are often unevenly distributed to high-income households (Morales-Novelo *et al.* 2018; Abramovsky *et al.* 2020) and subsidies do little to address problems with water quality. Additionally, while improvements to water-related infrastructure are critical for improving household water (Tortajada 2014), they are ineffective if the improvements interrupt service for prolonged periods. To address this issue, temporary connections to improved water supplies could be implemented prior to the commencement of major construction (Yazdani *et al.* 2011) and monitored to ensure they are benefitting residents. Beyond infrastructure, regular communication between COSANPA and the residents of neighborhoods most impacted by water problems (i.e., informal settlements and *baixadas*) will be critical for ensuring that new water lines are maintained and problems are quickly addressed (Kayaga 2013).

Additionally, our ethnographic data suggest that households experience numerous problems with water (i.e., chronic intermittency, low pressure, and variable quality) not captured by HWISE due to its emphasis on access and 'having enough water.' Households reporting these problems were also more often water secure than insecure, further indicating a disconnection between HWISE and the water insecurity experiences observed in Belém. Thus, like Badhwa *et al.* (2022) who found the HWISE instrument 'insufficient' for capturing household water experiences in the Galapagos, we found it to underestimate household water insecurity in Belém.

Coping to be water secure

Persistent problems with intermittent water service and concerns regarding discoloration, sediment, and odor encouraged residents to adopt numerous coping strategies. However, with coping strategies, there are trade offs (Achore *et al.* 2020; Venkataramanan *et al.* 2020), and the strategies employed in Belém do not necessarily guarantee improved access or quality. As in other contexts with an intermittent water supply (Galaitsi *et al.* 2016), households in Belém often rely on clandestine connections to access municipal water. While these clandestine connections bypass the expense and bureaucracy of a municipal connection, they decrease the overall capacity of the water supply network and further contribute to problems of intermittency (Unidade Coordenadaora do Programa Belém 2020).

When municipal water is available, residents store it in containers ranging in size from 5L buckets to the large 200L + *caixa d'agua* to ensure access during interruptions and periods of low water pressure. While water storage can help mediate intermittency, the prolonged storage of water can encourage bacterial growth within containers, undermining quality (Mastinhe *et al.* 2014). In HSES households located in multistory condominium complexes, water pump systems, maintained by condominium personnel, ensure that large *caixas d'agua* are kept full. In contrast, residents of LSES households with sufficient funds rely on makeshift pumps, prone to failure, to fill their individual *caixas d'agua*.

Like Matos de Queiroz *et al.* (2013), participants in this study perceived purchased water to be safer than municipal water. However, studies of bottled water sold in Belém found them to contain contaminants (Neta *et al.* 2012), and the 20 L *garrafões* sold in *baixada*s are often just tap water with added dyes and salt (Globo Comunicação e Participações 2016). Additionally, even if water is clean when purchased, opening and closing bottles throughout the day can introduce contaminants (Profitós *et al.* 2014).

Theoretically, residents of Belém should have ample access to water. The city is in a region of high rainfall and surrounded by large bays and rivers. Unfortunately, high levels of contamination with raw sewage and other organic and inorganic waste (e.g., trash, rotting food, tires, algae) have made these abundant natural water sources unviable alternatives to treated municipal and purchased water (Pegado *et al.* 2012; Mansur *et al.* 2018). Unlike in other regions of Brazil (Teston *et al.* 2018), in Belém, there is no cultural norm of collecting rainwater. While several studies have examined the possibility of rainwater systems for public buildings and private households in Belém (Cardoso-Castro *et al.* 2017; Cardoso *et al.* 2020), it has not been widely implemented. Only two households in our study reported collecting rainwater as a coping strategy for meeting household water demands.

In sum, access to sufficient water is ubiquitous in Belém. However, our study reveals that access does not guarantee household water security. To be water secure, especially in LSES homes, requires the successful management of intermittent and low-quality municipal water and the purchase of drinking water. While coping strategies are a type of agency taken to insulate against resource insecurity (Collins *et al.* 2024), in Belém, coping strategies appear to be a 'by-product' of chronic water insecurity that, similar to Sakar's (2022) observations of coping strategies in urban Kenya, impact households as much as the initial water insecurity. This suggests that future research and objective measures of water insecurity must consider the costs and benefit of household coping strategies, particularly when access is achieved, but stability of access and quality remain uncertain.

LIMITATIONS

There are a few limitations that impact the generalizability of our findings. First, households were purposefully selected to meet the criteria of a longitudinal study of infant health and development, meaning we did not collect data in homes without children. Second, like most other studies of water security in low- and middle-income countries, our reliance on adult women as participants limited our ability to capture experiences of other household members, such as adult men and children. Third, as we only applied the locally developed HWIU instrument in a sub-sample of LSES households, our ability to understand household water infrastructure and utilization in higher-income homes is limited. Finally, we were unable to include objective measures of water quality. However, these data have been collected and will be reported in a future manuscript.

CONCLUSION

This is one of the few studies to investigate household water security in the urban Amazon and to explore experiences in high- and low-income homes. Despite piped municipal water, LSES households reported issues of intermittent supply, low pressure, and variable quality not captured by HWISE. This led us to develop the HWIU, which revealed that regardless of household water security status, households experience co-occurring water problems. This finding stresses the importance of local instruments grounded in ethnographic understanding as otherwise we risk underestimating the true extent of household water insecurity.

The HWIU offers a model for doing so. It is simple and adaptable. Recording all points of water access within and immediately outside a household can be accomplished anywhere, and doing so provides ethnographic insights into exactly what sources of water participants consider themselves to have access to, how the water from those sources is used, and the experiences participants have with them. Applied prior to the application of other measures, the HWIU allows the wording of questionnaires to be adjusted appropriately, incorporating local terms, and the more purposeful investigation of water sources identified as important by participants, particularly when resources such as water quality testing kits are limited. Most importantly, when applied alongside other measures of water insecurity, the HWIU allows for further investigation of water insecurity experiences. For example, while in Belém, the HWISE captured the common experience of interruptions to water service, the HWIU revealed that the interruptions households experienced are intermittent in nature, accompanied by other water quality problems, and that households cope by storing water in anticipation of interruptions.

Additionally, our finding that both low- and high-income households experience water insecurity further challenges the notion that income buffers against inadequate and unsafe water (Stoler *et al.* 2020). While greater income may allow households to better cope with water insecurity, it does little to address structural concerns resulting from rapid and inadequate infrastructural development. Finally, while coping strategies allow households to access water, their cost must be considered within assessments of water security. Households will go to great lengths to access water. However, these strategies often come with a cost and, often, do not guarantee adequate water. By not considering the cost and outcome of coping strategies, we risk underestimating the impact of water insecurity. Future studies should carefully consider if coping strategies, successful or otherwise, result in water security.

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ETHICS STATEMENT

Free and informed consent of the participants or their legal representatives was obtained, and the study protocol was approved by the appropriate Committee for the Protection of Human Participants, by the Comissão Nacional de Ética em Pesquisa (CONEP) (número de parecer 4.043.620), the Brazilian federal agency that reviews international research with human subjects, and the Ohio State University Institutional Review Board (IRB) (2020B0014).

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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