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The embodiment of water insecurity: Injuries and chronic stress in lowland Bolivia

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Abstract

Water is critical to health and wellbeing. Studies have theorized that problems with water can become embodied, yet few studies have quantified this. Therefore, we first sought to understand the lowland Bolivian water environment of Tsimane' forager-horticulturalists. We assessed the water environment holistically, using objective measures of water quality and water services (Joint Monitoring Programme's drinking water services ladder) and subjective measures, including perceived water safety and water insecurity experiences [Household Water Insecurity Experiences Scale (HWISE)]. We tested how water service levels, perceived water safety, and water fetching frequency were associated with HWISE scores using Tobit regression models among 270 households. We then tested if and how water becomes embodied via self-reported water-related injury and a chronic stress biomarker, hair cortisol concentration (HCC). Results demonstrated that, compared with households using surface water, households with basic water services had HWISE scores 1.59-pts lower (SE = 0.29; P < 0.001). Ingestion of water perceived to be "bad" and more daily water-fetching trips were associated with higher HWISE scores. Twenty percent of households reported prior water-related injuries, with women most commonly injured. In logistic regressions, each point higher HWISE score was associated with 28% (95%CI:1.16–1.41; P < 0.001) higher odds of injury. Basic water services compared to surface water was associated with 48% lower odds (OR = 0.52; 95%CI:0.33–0.82; P = 0.005) of injury. Finally, using linear regressions among 332 adults, HWISE scores were not associated with HCC. Past

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Credit statement

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Declaration of competing interest

The authors declare they have no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2021.114490.

water-related injury was associated with higher HCC (Beta = 0.31; SE = 0.09; P = 0.029) among women, but not men. Relying on unimproved water services compared to surface was associated with 46.2% higher HCC for women (Beta=0.38; SE=0.14; P=0.048) and 55.3% higher HCC for men (Beta=0.44; SE=0.15; P=0.044), respectively. Overall, our findings demonstrate that water insecurity can become embodied through water-related injuries and elevated HCC. Improving water service levels through an equity lens may help ameliorate water insecurity and its accompanying negative health effects.

Keywords

Water insecurity; JMP drinking water ladder; water services; Water-related injury; Chronic stress; Hair cortisol concentration

1. Introduction

Reliable access to sufficient clean water is imperative for health, nutrition, and overall well-being (Rosinger and Young, 2020). Yet, 785 million people worldwide lack improved (i.e., safe) drinking water sources on their premises (World Health Organization, 2019). This scarcity increases risk for water-borne illness from exposure to contaminated water (World Health Organization, 2019) and injury from fetching and carrying heavy loads of water potentially long distances, sometimes on rugged terrain (Venkataramanan et al., 2020). Water contamination contributes to 1.8 million deaths annually (Bakker, 2012; Landrigan et al., 2018), and the health toll of increased stress and other morbidities from inadequate access to clean water is even greater (Wutich et al., 2020a). In the face of climate change and more frequent droughts and floods, water availability problems are expected to increase worldwide, even in water-rich environments (Gleick, 2014; Konapala et al., 2020).

In the Amazon, frequent flooding, intermittent droughts, fires, and mining all jeopardize water security and can reduce trust in water sources and disrupt the availability of and access to acceptable water for drinking, cooking, bathing, and other domestic needs (Tallman, 2019). A key characteristic of water insecurity in the Bolivian Amazon is the reliance on surface waters, like rivers, ponds, and streams, which are often turbid and contaminated (Rosinger, 2018). While reliance on surface waters has declined worldwide, it is much higher in rural areas in low-income countries (World Health Organization, 2019). Development and engineering projects from both governmental and non-governmental organizations (NGOs) have worked to reduce reliance on surface waters (Brikké et al., 2003; World Health Organization, 2019). However, these small, community water sources are often not properly maintained; 30–60% are inoperable at a given time, causing frustration and continued reliance on surface waters that take a toll on both mental and physical health (Brikké et al., 2003). Water sources that are unimproved, like open wells or springs, may cause increased stress as they are contaminated more easily and/or may lack required tools (e.g., rope and bucket) to fetch water.

Household water insecurity is defined as the inability to access and benefit from sufficient, reliable, and acceptable water for well-being and a healthy life (Jepson et al., 2017), which can be the result of problems of too much, too little, or poor quality water (Rosinger and

Young, 2020). The drinking water service ladder is an adjacent measure developed by the Joint Monitoring Programme (JMP) which refers to the accessibility, availability, and quality of the main water source ranging from surface water at the low end to safely managed water in people's homes at the high end (World Health Organization, 2019). Both of these concepts are useful for understanding people's access to and experiences with water (Wutich et al., 2020b).

An emerging way to conceptualize how water insecurity gets under the skin is embodiment (Rosinger and Brewis, 2020). As Krieger (2005:350) explains, "bodies tell stories about—and cannot be studied divorced from—the conditions of our existence." Understanding how water insecurity may affect health necessitates first understanding the relations between environmental and household conditions and water insecurity experiences.

There is growing consensus that lived experiences surrounding water insecurity negatively affect mental health through a variety of mechanisms, including the stress of constant uncertainty, environmental injustice, and worry of water-borne illness (Wutich et al., 2020a). Studies from around the world have demonstrated that water insecurity increases psychosocial distress, risk of depression, anxiety, and negative emotions like anger and frustration (Cooper-Vince et al., 2017; Ennis-McMillan, 2001; Krumdieck et al., 2016; Stevenson et al., 2012; Tallman, 2019; Workman and Ureksoy, 2017; Wutich and Ragsdale, 2008).

Water insecurity also takes a toll on physical health through injuries incurred during water fetching, particularly among women who are often responsible for water collection (Adams et al., 2020; Geere et al., 2018; Sorenson et al., 2011). While recent work has demonstrated that water insecurity and water access are associated with risk of injuries (Venkataramanan et al., 2020), little is known about whether these prior injuries increase objective markers of stress and whether this differs by sex in populations in which women are the primary water collectors.

While subjective measures of perceived stress in relation to water insecurity are evidence of embodiment, a key challenge in biocultural analyses has been tracking pathways through which the lived experience is embodied (Leatherman and Goodman, 2020). Thus, examining bio-markers of stress in relation to experiences surrounding water acquisition or scarcity may unveil the chronic toll of water insecurity that people may not always perceive (Brewis et al., 2020; Rosinger and Young, 2020; Wutich, 2020). This process has previously been described as the physical environment (e.g., water insecurity) literally getting "under the skin" (Krieger, 2005; McDade et al., 2007; Worthman and Kohrt, 2005). Physiologically, this process can be marked by a rise in the stress hormone cortisol, which is often released in response to a perceived threat, to mobilize energy stores and suppress certain immune processes (Russell et al., 2012; Sapolsky et al., 2000). While this acute response is adaptive for dealing with immediate threats, chronic activation of this stress response in the hypothalamic-pituitary-adrenal (HPA) axis takes an enormous toll on long-term physiological and psychological health (McEwen, 2007; Wosu et al., 2013).

As bodies are situated in specific environments, in this case entangled with ongoing water problems, understanding these pathways from water insecurity to risk of injury from water fetching to chronic stress within diverse environments can provide a window into the concept of embodiment through local/situated biologies (Leatherman and Goodman, 2020; Lock, 2017; Worthman and Kohrt, 2005). In areas without clean, reliable, and sufficient water, the toll of water insecurity is imprinted on bodies. The uncertainty of whether water will cause sickness (Krumdieck et al., 2016; Rosinger, 2018), insufficiency of water for preventing dehydration (Bethancourt et al., 2021a; Perrier et al., 2013; Rosinger, 2018), inequality in access to water (Wutich et al., 2020a), and the mental and physical toll of injury-prone water fetching tasks (Adams et al., 2020), are all potential sources of chronic cortisol activation. Thus, the role of water in people’s lives may be a critical yet overlooked factor in the pathway to development of chronic diseases (Rosinger and Young, 2020).

Only a few studies have empirically tested components of the embodiment of water problems on stress bio-markers. They have either examined how water access (Brewis et al., 2019) or water insecurity (as part of an index of vulnerability to a variety of resource insecurities) (Tallman, 2016) were associated with blood pressure, sometimes used as a stress biomarker. One study tested the association between “feeling unsafe” while collecting water or using sanitation facilities and hair cortisol concentration (HCC), a biomarker of chronic stress, among women (Phaedra et al., 2014). Yet, to date no studies have conducted a holistic examination of water insecurity in relation to chronic stress via HCC.

To address these research gaps and better understand the pathways from water insecurity to injury and chronic stress, this study empirically examines how water insecurity may become embodied among Tsimane’, an indigenous Amazonian population in Lowland Bolivia.

Our first objective is to describe the water environment among Tsimane’ households. We do this by describing objective water quality analyses, perceptions of drinking water safety, the JMP drinking water service ladder, water-fetching activities, and water insecurity experiences using the Household Water Insecurity Experiences (HWISE) scale. We next test how water service level, perceived water safety, and daily water fetching trips are associated with HWISE scores. We hypothesized stepwise lower HWISE scores as water services improved and higher HWISE scores as perceived water safety worsened and number of daily trips increased.

Our second objective is to test if water is embodied in 1) water-related injuries and 2) chronic stress measured via HCC. We first hypothesized that higher HWISE scores and number of daily water-fetching trips would be associated with greater odds of injuries. Second, we hypothesized that improved water service levels would relate to a stepwise decline in odds of injury. Third, we hypothesized that greater household experiences with water insecurity (HWISE and perceived water unsafety) and prior water-related injuries within a household would be associated with higher levels of individual HCC. We predicted that any negative household experience with water, like water-related injuries, would make the risks of fetching water more acute particularly for women. Thus, while the injury only happens to a single family member, the event may cascade throughout the household. Finally, we predicted that water service levels would be inversely associated with HCC, such that those relying on surface water would have the highest HCC (highest chronic stress) with sequentially lower HCC moving up the water service ladder.

2. Methods

2.1. Research site

This study was conducted among Tsimane' forager-horticulturalists in Beni, Bolivia during April–May 2019. Tsimane', an indigenous population of ~16,000, are undergoing lifestyle and built environment changes as some communities are beginning to gain access to electricity, wells, and protected hand-pumps through governmental and non-governmental development projects (Rosinger, 2018). As such, many Tsimane' rely on surface and unimproved water sources and face high burdens of water-borne pathogens (Blackwell et al., 2011), especially given that few individuals boil or treat their water (Dinkel et al., 2020). Thus, the majority of the communities still lack access to clean water (Dinkel et al., 2020; Rosinger and Tanner, 2015).

2.2. Participant recruitment

We attempted exhaustive sampling in five of the ~100 Tsimane' communities. Villages were selected to represent variation in access to water sources and distance to the main market town of San Borja, ranging from 2 to 10 h in travel (Bethancourt et al., 2021). Four of the villages were only accessible via canoe, while one was accessible via car or motorbike. In each village, we recruited >90% of all households to participate in a household survey; both male and female household heads were invited to participate, though men were sometimes unavailable due to labor activities or travel. When both were present, they were interviewed together, providing a single response to household questions and each responding to individual-level questions. If one was present, they were interviewed on the household's behalf.

2.3. Ethical approval

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board of Pennsylvania State University in the US and by Universidad Autónoma del Beni Jośe Ballivián in Bolivia. Permission was also obtained from the Gran Consejo Tsimane' in San Borja, Bolivia, from community leaders in the sampled communities, and all participants provided informed oral consent.

2.4. Water environment

Drinking water service levels.—We asked participants about the main drinking water source they used, and the duration of a water-fetching round-trip. We then classified households according to the JMP ladder for drinking water services (hereafter, JMP ladder) (World Health Organization, 2019). In this context, the Maniqui River, streams, and ponds/ lagunas were classified as surface water; unprotected springs and unprotected open wells were classified as unimproved water; and protected handpumps/boreholes within 30 min round-trip of the household were classified as basic water access. Limited access was defined as when the improved source was greater than 30 min round-trip. No water sources used by Tsimane' fell into the safely managed categories (improved source on premises).

As only two households had limited access, they were grouped with those with basic access due to cell size (all results were consistent if grouped instead with those with unimproved access).

Water fetching trips.—We asked adults how many daily trips their household (any member) took to collect water because greater trip frequency increases the physical demand and opportunity for injury (see 2.5).

Objective water quality.—During community meetings and household interviews, we inquired about all water sources used in the community for drinking water. We visited all sources (n = 47) reported among the five communities. We took water samples from each source to measure water turbidity, pH, conductivity, salinity, and temperature using a YSI ProDSS meter following protocol guidelines (YSI ProDSS, 2017). We also collected water samples from these water sources following USGS guidelines (Wilde et al., 1998) to measure presence of hydrogen sulfide-producing bacteria (e.g., Salmonella, Citrobacter), an indication of fecal contamination (Hach Pathoscreen).

Perceived water quality.—Tsimane' tend to define water cleanliness or dirtiness through organoleptic properties, such as turbidity or clarity, presence of trash or dead animals, or bad smell (Rosinger, 2018). This concept of "bad" or dirty water is captured with the word "*achij*" (in Tsimane'). As an indicator of perception of water uncleanliness/contamination, we asked how frequently they or anyone in their household drank water that looked, tasted, or smelled bad "*achij*" (hereafter "bad water") in the previous 4 weeks. Response options were never, rarely (1–2 times), sometimes (3–10 times), or often/always (11+ times), scored as 0, 1, 2, or 3, respectively.

Experiences with water access, use, and reliability.—During surveys with household heads, we used the cross-culturally (including lowland Bolivia) validated HWISE scale (Young et al., 2019a, 2019b). The scale assesses the frequency in the previous 4 weeks that anyone in the household experienced any of 12 potential negative emotions (e.g., worry, anger, shame) or disruptions in daily life (e.g., inability to wash clothes, hands, or body) due to water problems. Response options were never, rarely (1–2 times), sometimes (3–10 times), or often/always (11+ times), scored as 0, 1, 2, or 3, respectively. Scores for the 12 items were summed for a total score range of 0–36; a score of ≥12 was defined as water insecurity (Young et al., 2019a). The Cronbach's alpha for the 12-items was 0.80, suggesting reliability of the scale in this setting. We supplement these with fieldnotes about water experiences taken by the team throughout fieldwork.

2.5. Outcome 1: water-related injury

We asked adults whether anyone in the household had ever been hurt or injured fetching water, with follow-up open-ended questions about the specifics of the injury, i.e., who was injured and the type of injury, following Venkataramanan et al. (2020). Qualitative analysis of the responses yielded two general types of injuries: injuries from falls and injuries from stepping on large thorns.

2.6. Outcome 2: hair cortisol concentration (HCC)

As our measure of chronic stress, we analyzed HCC from all household heads who provided a hair sample. Because of diurnal fluctuations in cortisol and day-to-day variability, individual measures of cortisol in saliva, urine, or blood capture only short-term stress responses (Stalder and Kirschbaum, 2012) and are not well-suited for measuring the retrospective chronic stress we hypothesized would result from water insecurity. In contrast, HCC from hair collected close to the scalp is considered an objective measure of recent chronic stress because cortisol is continuously incorporated into hair as it grows (Russell et al., 2012; Stalder and Kirschbaum, 2012; Wosu et al., 2013). Given estimated hair growth of ~1 cm/month (Russell et al., 2012; Stalder and Kirschbaum, 2012), we collected and assayed the 1.5 cm of hair closest to the base of the scalp to match HCC levels as closely as possible to the 4 week timeframe covered by the HWISE scale. Samples of hair were cut at the base of the posterior vertex of the scalp or from the temporal or parietal regions of the scalp for individuals lacking at least 1.5 cm of hair in that region. Hair samples were stored in aluminum foil pouches at room temperature and processed and assayed using the Salimetrics high sensitivity salivary cortisol enzyme immunoassay in the Biomarker Core Laboratory at Pennsylvania State University. It was assayed following the manufacturer's instructions with intra- and inter-assay coefficients of variation of 7.1% and 10.1%, respectively, with full details described elsewhere (Bethancourt et al., 2021).

2.7. Covariates

To distinguish the role of water insecurity on chronic stress from other potential stressors (Russell et al., 2012, 2015), we controlled for individual and household characteristics that can affect stress, including: age (either individual or the female household head's age for household level analyses [for 12 households the age of the male was used when no female was present)]; body fat percentage (%BF) as measured with a bioimpedance Tanita scale; lactating status for women; food insecurity measured by the household food insecurity access scale (HFIAS) (Coates et al., 2007); household size adjusted by adult equivalent of water needs from the household composition using European Food Safety Authority (European Food Safety Association, 2010) water requirements ratios (children aged >8 years multiplied by 0.58; children 8–16 multiplied by 0.85); perceived socio-economic standing in the community as measured by the MacArthur Ladder (Giatti et al., 2012); and total household income over the prior month.

2.8. Statistical analysis

All analyses were performed in Stata V.15.1 (College Station, TX). We natural log-transformed HCC and household income since both were left skewed. The natural log-transformed HCC was normally distributed (Supplemental Figure 1). For all regression analyses, we controlled for community fixed effects with robust standard errors clustered at the community level.

To achieve our first aim, we present descriptive characteristics of the water environment within which Tsimane' live. Next, to examine how these characteristics are associated with experiences of water insecurity, we estimated tobit regression models that regressed HWISE score on JMP ladder, drinking "bad water", and daily water-fetching trips, adjusted for covariates since the HWISE scale was asked at the household level. We use tobit regression, which allows for an examination of censored continuous outcomes such as water insecurity data, because 0 and 36 are the lower and upper bounds of the HWISE scale (Stoler et al., 2020).

For our second aim, we examined how water insecurity is embodied by testing its association with two health outcomes: injury and HCC. First, since water-related injury was a binary variable, we used multiple logistic regression models at the household level to estimate its odds by HWISE score, JMP ladder, and daily water-fetching trips adjusted for covariates. Second, we estimated ordinary least squares (OLS) linear regression models at the individual level to assess how HWISE scores, perceived water safety, water-related injury, and JMP ladder were associated with HCC for men and women, separately, adjusting for covariates because HCC is a continuous variable. To provide interpretable magnitudes of effect of natural log-transformed HCC, we used post-estimation marginal standardization using the margins command and the following syntax:

$$\mathrm{Expression}(\exp(\mathrm{predict}(\mathrm{eta}))_{*}(\exp((b[/\mathrm{var}(e\,.\,\ln(\mathrm{HCC}))])/2)));$$

This method adjusts for the range of covariates and back-transforms HCC with unbiased estimates and standard errors of the variance (Huber, 2019).

2.9. Analytic samples

Our analytic sample for household level analyses included all non-pregnant, household heads aged 16 years and over, yielding 270 households. Approximately 80% of the household heads who participated in the survey provided hair samples for measuring HCC. Of those who provided hair samples, 20 males and 12 female household heads were excluded due to errors in one assay and another was excluded for outlying HCC values (>1500 pg/mg). The analytic sample for HCC analysis, therefore, was 171 men and 161 women with full covariate information.

3. Results

3.1. Water environment among Tsimane’

Women were primarily responsible for water in 58.1% of households, or they shared responsibility (often with their children) in 20% of households; men (12.2%), children (8.5%), or other household members (1.1%) were responsible for water in the remaining households. On average, households took 2.3 (range: 1–10) daily trips to collect water at 7 minutes (range: 1–60) per round-trip (Table 1).

Drinking water service levels.—According to JMP ladder classifications, 23.3% of the 270 households used surface water as their primary drinking water source, 45% had unimproved services, and 31.1% of households had basic water services (Table 1). Only two (0.7%) households, which used protected handpumps, reported that their roundtrip took more than 30 min, thus classified as limited service.

Experiential.—The mean HWISE score was low at 2.0 (SD = 2.8), and only 2% of households had an HWISE score ≥12, indicative of water insecurity (Table 1; Supplemental Figure 2). However, substantial variation of scores within and across communities existed (Supplemental Figure 3). While HWISE scores were low, several Tsimane' described issues with water sources and mixed experiences with water fetching. For example, one women stated "fetching water is hard/stressful because the path [to fetch water] is really bad–it's muddy, slippery." Another household complained that the open well they used needed maintenance and the water was dirty. They said they had to extract all the water to clean the inside of the well and remove the "black gunk" to make the water acceptable for use again. Others complained that kids would throw batteries and other trash (e.g., beer cans) into open wells, that natural debris from trees would fall into them, and that people sometimes dropped their small jerrycans inside it. Further, households commonly complained about reaching an open well and being unable to extract water due to a missing water-drawing bucket. There were even issues with improved water sources, as exemplified in one community where the water from a relatively new protected handpump was highly turbid (the outlier noted below), contaminated, discolored, and metallic tasting. There, people resorted to fetching water from the river because it tasted and looked more acceptable.

Beyond how people felt about water sources, the actual process of fetching water was related to a range of sentiments. Some sentiments were more negative and related to the fatigue from carrying heavy loads of water. Other sentiments were neutral as people reported seeing water fetching as a usual part of daily life and that they were accustomed to it. Finally, some people reported positive sentiments, such that they felt happy because water is necessary for cooking and life.

Objective quality.—The water quality testing of 47 sources found that quality tracks the JMP ladder in the expected direction, with improving quality moving up the ladder (Table 2). Nearly all samples from surface sources tested positive for fecal contamination and had higher turbidity. Unimproved water service varied by type of water source; 40% of the unprotected springs samples tested positive for fecal contamination, whereas 86% of the open uncovered wells samples tested positive. However, the turbidity was low (3.3–4.5 NTUs) for unimproved water. For limited/basic access service, 44% of the samples tested positive for fecal bacteria, and the turbidity was low (13.8 NTU, with one outlier of 93), as 8 of 10 pump wells had turbidity below the acceptable threshold of 5.

Perceived safety.—Despite the high level of fecal contamination and turbidity in surface waters, when asked about perceived water safety or "bad water" consumption in the past month, 84.4% of households reported they did not consume what they considered "bad water," while 8.9% reported this 1–2 times and 6.7% reported 3–10 times.

3.2. Predictors of water insecurity experiences

Only the limited/basic drinking water service level was associated with HWISE score adjusting for covariates. Those with limited/basic service scored 1.59-pts (SE = 0.29; P < 0.001) lower on the HWISE scale compared to those who used surface water (Fig. 1;

Supplemental Table 1). Unimproved service was not associated with lower HWISE score compared to surface water.

Perceived water safety was strongly associated with higher HWISE scores. Households that reported consuming “bad water” 1–2 times and 3–10 times in the past month scored 2.05-pts (SE = 0.85; P = 0.017) and 2.62-pts (SE = 0.73; P < 0.001) higher, respectively, on the HWISE scale than those that reported never drinking “bad water”. Finally, each additional daily trip to fetch water was associated with a 0.35-pt (SE = 0.16; P = 0.028) higher HWISE score.

3.3. Water-related injury

Tsimane’ often fetch water by going to the river where the riverbanks can be very steep, up to 50–60 feet in some of the study communities, which increases the chances of falls especially when carrying water or if it’s slippery. Of the 270 households, 55 (20.4%) reported that someone in their household had previously been injured fetching water. The majority of injuries occurred among women. When asked who had been injured, 38 of the 55 (69.1%) households reported the female household head, 15 (27.3%) reported the male household head, seven (12.7%) reported a child, and one (1.8%) reported another household member. Only two major types of injuries were reported. The majority (91.0%) of injuries were related to slips and falls while retrieving or carrying water. Nine percent were foot-related injuries from stepping on large thorns while fetching water, as many Tsimane’ do not wear shoes when fetching water. One older woman told us that injuries often occur after heavy rains. She said, “last year [during the rainy season] when it was wet, I fell and cut my elbow and bruised it badly.”

HWISE score was positively related with injury risk (Fig. 2; Supplemental Table 2). Each point increase in HWISE score was associated with 28% (95% CI: 1.16–1.41; P < 0.001) higher odds of a household water-related injury. Further, limited/basic water service was a protective factor against injuries. Compared to households relying on surface water, households with limited/basic water access had 48% (OR: 0.52; 95% CI: 0.33–0.82; P = 0.005) lower odds of water-related injury. Use of unimproved water services was not associated with odds of injury. Water insecurity experiences, like anger over the water situation, are often interwoven with injury. One man who reported falling and hurting his buttocks the prior week stated: “[Getting water] is hard because it’s far. I feel mad sometimes. I get mad when my wife doesn’t bring it and I have to go get it.”

3.4. Hair cortisol concentration

Among the sample of 171 men and 161 women household heads, mean HCC was 23.3 pg/mg (SD = 43.8) and 13.6 (SD = 20.2), respectively.

Contrary to our hypothesis, experiences of water insecurity (HWISE score) were not associated with elevated HCC in men or women (Table 3). Reported consumption of “bad water” was not associated with HCC for men. However, women from households that reported sometimes consuming “bad water” had marginally higher HCC (B = 0.22; SE = 0.09; P = 0.075), which translated into 24.6% higher HCC, compared to women from households with no “bad water” consumption in the previous four weeks.

There was a gendered association between water-related injury and HCC. History of water-related injury in the household was significantly associated with 36.3% higher HCC among women (Beta = 0.31; SE = 0.09; P = 0.029), but not men.

The JMP ladder showed a distinct pattern with HCC for both men and women. Compared to surface water, men and women with unimproved services had 55.3% and 46.2% higher HCC, respectively (Beta = 0.44; SE = 0.15; P = 0.044 for men; Beta = 0.38; SE = 0.14; P = 0.048 for women). Limited/basic water service, in contrast, was not associated with HCC compared to surface water.

Using marginal standardization, we estimated the predicted HCC in relation to the JMP ladder categories. Pairwise comparisons indicate men with unimproved services had HCC 8.5 pg/mg higher (95% CI: 2.7–14.2) than those using surface water while those with basic water service did not have higher HCC. The same pattern was observed for women, as those with unimproved services had 4.8 pg/mg (95% CI: 1.3–8.3) higher HCC than those using surface water (Fig. 3a–b).

4. Discussion

We sought to understand objective and subjective experiences of water insecurity and whether it becomes embodied in injury and chronic stress among Tsimane' in the Bolivian Amazon. First, we found that objective water quality tracked the JMP ladder; better water services had better water quality. As for our hypothesis of a stepwise reduction in HWISE scores with improving water services, we found that basic, but not unimproved water services were associated with lower HWISE scores among Tsimane'. We also found that "bad water" consumption and higher number of daily water-fetching trips were positively associated with HWISE scores.

Second, in support of our hypothesis, we found that higher HWISE scores were associated with higher odds of injury, whereas limited/basic, but not unimproved, service levels were associated with reduced odds of injury compared to surface water. Further, we found that subjective experiences of water insecurity were not associated with HCC as hypothesized. However, water-related injury was associated with higher HCC for women, but not men. Finally, we found that unimproved services were associated with significantly elevated HCC, which contrasted with our hypothesis of a stepwise reduction in HCC with better drinking water services beyond surface water.

4.1. Tsimane' water environment and water insecurity experiences

Overall water insecurity (HWISE) scores were low (mean 2) despite the fact that Tsimane' households have limited access to clean, improved drinking water sources and frequently rely on water that is turbid and contaminated with fecal bacteria. Only 2% of households had scores of ≥12, defined previously as the provisional threshold for water insecurity (Young et al., 2019a). A number of sites where HWISE has been implemented had low mean site scores similar to Tsimane' (Stoler et al., 2021). For example, households in the Pune, India site had a mean score of 1.6 for the HWISE 12, while still demonstrating accuracy, validity, and reliability of the scale (Young et al., 2021). This means that water problems may exist even with low HWISE scores. Ultimately, any non-zero scores may indicate water problems, similar to the food insecurity scales where an affirmation to any question indicates food insecurity (Coates et al., 2007). In this water-rich environment, Tsimane' may not have a variety of water insecurity experiences as they rarely experience scarcity yet still experience water problems with 61% having an HWISE score greater than 0 (Supplemental Figure 2). Only ~15% stated they consumed "bad" or "*achij*" water in the past month, though objective water quality results demonstrated high turbidity and frequent fecal contamination in surface water and some of the unimproved water sources, which together accounted for more than half of households' water. Given how relatively few Tsimane' households reported drinking water they perceived as being unsafe, water risk may not be at the forefront of their minds.

One previous study found high levels of water insecurity among Tsimane' after a historic flood (Rosinger, 2018). A few key differences may explain the contrasting findings. Prior work used a different 9-question scale, two of which assessed the effects of flooding, and a binary (affirmative or not) scoring system. Although both studies were conducted during a similar time-period, i.e. after the rainy season, extreme flooding did not occur prior to data collection in the present study. Therefore, it is unsurprising that scores in the prior study were higher as flooding can increase multiple dimensions of water insecurity.

Several key environmental and household factors, such as water service level, daily fetching trips, and perception of water safety, were significantly associated with HWISE scores in the current study. Basic water access, which meant a protected handpump, was associated with lower HWISE scores. This is consistent with the prior study in the region that found that handpumps were associated with lower water insecurity (Rosinger, 2018). On the other hand, consuming "*achij*" water that looked, tasted, or smelled bad was associated with higher HWISE scores. This is similar to prior work in Ghana which found that participants that worried about their water quality had higher water insecurity scores (Kangmennaang et al., 2020). This suggests that water security could be improved by increasing investments in improved water sources in every community.

4.2. Embodiment of water insecurity: injury and HCC

Krieger (2005) notes, "bodies tell stories that often—but not always—match people's stated accounts". Water insecurity marks the body via scars, bone breaks, and bruises from water-fetching injuries. Here, we found that ~20% of households reported a prior water-fetching injury among a household member, mostly caused by falls. This aligns with previous research that found ~15% of Tsimane' households, and a greater proportion of women, reported injury (Rosinger, 2018). However, even those who did not report acute water-fetching injuries complained about the pain, particularly in their lower backs and arms, caused by carrying water daily. Thus, the percentage of reported "injuries" likely under-estimates the amount of chronic physical pain embodied from water insecurity in this site.

Our results also correspond with other research on water insecurity and injury risk. In a study in 19 low- and middle-income countries, injury during water fetching was reported among ~13% of respondents (Venkataramanan et al., 2020). Across those sites, each point increase on the HWISE scale was associated with 9% higher odds of injury, while reliance on surface waters (relative to piped water) was associated with 97% higher odds of injury. Our findings were similar as each point higher on the HWISE scale was associated with 28% higher odds of injury, while reliance on surface water (relative to basic service level) was associated with 91% higher odds of injury. Importantly, for development and engineering projects, access to protected water sources like hand-pumps translated into 48% lower odds of injury. These findings indicate that provision of basic water services, like hand-pumps, has the potential to not only improve water security but also reduce water-related injuries in the Amazon.

While injury is a story the body tells often visibly, chronic stress is often invisible. Krieger continues, “bodies tell stories that people cannot or will not tell, either because they are unable, forbidden, or choose not to tell” (Krieger, 2005). HCC is one way that bodies tell the untold story about the embodiment of water insecurity. This study is the first to explicitly test how experiential and objective measures of water insecurity relate to HCC levels. We found that for women, but not men, water-related injury was associated with significantly higher HCC. Tsimane’ women are primarily responsible for water in Tsimane’ households and the burden of water-fetching falls on them. This resulted in the majority of injury cases reported among women. Thus, women may be more aware and wary of water-related injuries (Geere et al., 2018). Our results suggest that Tsimane’ women may not only be stressed by the potential of injury but also by the daily exertion necessary to fetch water, particularly when going up and down slippery cliffs and riverbanks. Our results are consistent with research showing that the fear of injury or sexual assault increases perceived psychological stress (Bisung and Elliott, 2016), and thus this perceived stress is embodied in HCC. For example, higher HCC was found among women in Kenyan settlements who reported “feeling unsafe” collecting water or while using sanitation facilities (Phaedra et al., 2014); the higher HCC in that context was likely due to the risk/fear of sexual assault rather than injury of water collection. Our results illustrate the embodiment of gendered expectations of water-provisioning responsibilities in higher risk of water-related injury among Tsimane’ women and higher HCC associated with a household history of water-fetching injury.

While much work has demonstrated that negative experiences with water insecurity and water safety are associated with higher perceived stress and anxiety (Workman and Ureksoy, 2017; Wutich et al., 2020a, 2020b), we did not find an association between the experiential indicator of water insecurity (HWISE) and HCC. This finding is consistent with the two studies to date that also found only small or null relationships between blood pressure, used as a stress biomarker, and water access or water insecurity. In the Peruvian Amazon, no significant association was found between water insecurity and blood pressure (Tallman, 2016). In a study conducted in Nepal, blood pressure was only slightly elevated (~0.8–1.6 point higher mmHg) among women, but not men, in relation to having water more than 5 min outside the home (Brewis et al., 2019). Further, while problems with water quality and fear of injury can be stressful, our observations found that Tsimane’ are accustomed to many water-related aspects of life and certain aspects of fetching water are even enjoyable. Thus, it is impossible to neatly parse out all daily experiences with water and disease processes, here chronic stress, as much as a singular acute event like a major flood (Krieger, 2005).

Notwithstanding, our results among Tsimane' household heads indicated that unimproved water services were associated with 55% and 46% higher HCC for men and women in their respective models, compared to their counterparts using surface water. These results point to not only statistically significant differences, but practically large effect sizes with biological significance. The health effects of chronic stress and chronically elevated cortisol are well described (Sapolsky, 2005) as they are deleterious for the cardiovascular system, immune system, and cognitive function, as well as promote gains in body (particularly visceral) fat (Bjorntorp, 2001). Future work should continue to examine how inequities in access to improved water sources may lead to the development of chronic diseases and how local/situated biologies shape this process (Rosinger and Brewis, 2020).

4.3. Water services as inequity

Perceived inequity may help explain why unimproved water, which is classified as better on the JMP ladder than surface water, is associated with elevated HCC. Prior work suggests that those in the midst of lifestyle transitions may experience elevated stress as a consequence of increasing inequality (McDade, 2002). For Tsimane', who are increasingly visiting market towns and see piped water and clear bottled water, this could manifest as perceived inequity when they observe other communities or households, but not their own, receive access to improved sources. Individuals express a desire for clean water, but it may be too onerous (e.g., having to cross the river or travel greater distances) for some to reach improved sources (Rosinger, 2018). Households living farther away from the construction of improved water sources may experience increased stress and perceptions of disadvantage or inequality and feelings of dissatisfaction, especially if they no longer believe the river is clean. They may also feel a lack of control over their water situation and their ability to improve water sources, as efforts and investments in water infrastructure development have come from outside, often international, development projects (Rosinger, 2018). Such perceived lack of control may also contribute to higher psychosocial stress (Sapolsky, 2005).

The emotional distress caused by water insecurity often begins as feeling bothered and ruminating on the lack of control over the water situation (Mushavi et al., 2020). Psychosocial stressors surrounding water have been shown to reflect perceived inequities (Bisung and Elliott, 2016). Recent work among Tsimane' found that relative household and community wealth inequality was associated with higher blood pressure, but did not examine water access (Jaeggi et al., 2021). A prior ethnographic examination of Tsimane' perceptions of "a good life" found clean water to be the second most important item and part of a lifestyle model that increasingly favors market goods (Schultz, 2019). Understanding sources of variation within and across communities is important for addressing inequities in water security because not all Tsimane' households experience the same water problems. In Tsimane' communities, the unimproved water service level frequently means unprotected springs and open wells. The former often require more time to collect water; the latter are frequently contaminated when children throw sticks, batteries, and other trash into them and require great effort to be cleaned. Yet community members have been told repeatedly by NGOs that wells are a cleaner source of water than river water. This may generate confusion and uncertainty that could exacerbate stress. Thus, access to water sources may be an emerging source of inequality within this transitioning population. Therefore, equity is critical in development projects and provision of clean water.

4.4. Limitations

Limitations include the cross-sectional, retrospective design. While the timespan of HWISE mapped onto the HCC measure, future work should examine this relationship longitudinally to see how water insecurity changes with HCC. Future work should measure chronic stress in additional ways to further confirm our HCC results. Further, the low HWISE scores may have made it difficult to detect an association with HCC. Therefore, future studies in locations where HWISE scores are higher should be conducted to untangle experiential indicators of water insecurity and chronic stress.

Second, in regression models, the water quality results were not linkable to the water sources used by households as we lacked data on exact household water source. However, our results demonstrate that water quality was broadly captured by the JMP ladder variable and perceptually with the “bad water” variable.

Beyond the cross-population variability in HCC (Wosu et al., 2013), a variety of factors could influence intra-population variation in HCC for which we do not have data. These include differences in hair washing frequency (Stalder et al., 2017), time since hair was last washed (Rippe et al., 2016), and sun exposure to the area of the head from which hair was sampled (Wester et al., 2016). Based on our work in the area, we do not expect substantial variation in these.

Finally, this study may be subject to omitted variable bias, where some unmeasured variable may partially explain our findings. We attempted to limit this bias through the control of community fixed effects (Wooldridge, 2015), which accounts for clustering within community and potential time-invariant factors and unobserved heterogeneity that otherwise may not be captured. This analytic strategy presents more conservative standard errors (and p-values) compared to mixed-effects models which utilize random effects for community residence.

5. Conclusion

Overall, this study advances the water insecurity literature in two important ways. First, it combined experiential with objective indicators of the water environment to provide a robust understanding of how they interrelate and are associated with water security and well-being in the Bolivian Amazon. Second, it empirically tested the embodiment of water insecurity using an objective biomarker of stress, hair cortisol concentration. This study demonstrated that basic water services were associated with lower water insecurity and lower odds of water-related injury. While HWISE scores were not associated with chronic stress, unimproved water access was associated with 46–55% higher HCC than those relying on surface water. That water-related injury was associated with 36% higher HCC for women but not men, illustrates the invisible, yet gendered embodiment of chronic stress for those responsible for supplying household water. Our findings suggest that development projects can ameliorate water insecurity experiences, water-related injury, and chronic stress by designing better protection for water sources, and ensuring equitable access to at least basic water services across communities and households.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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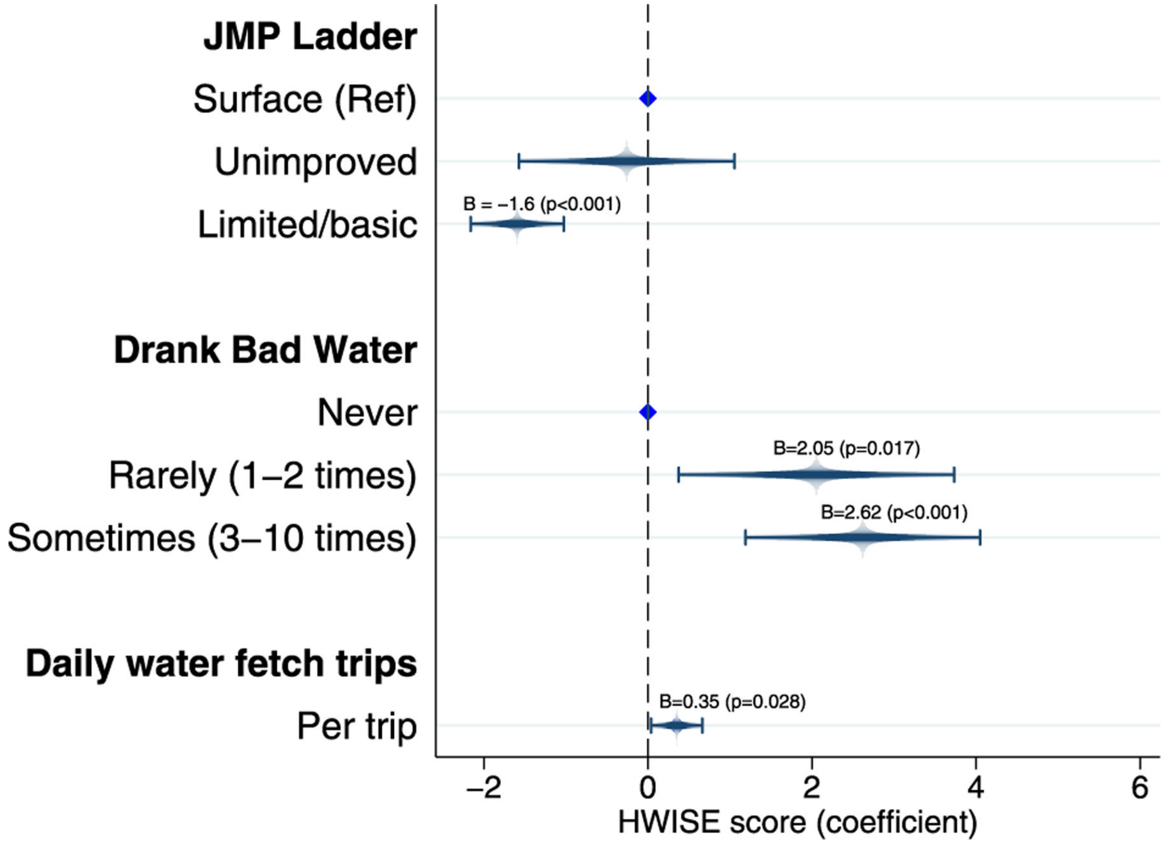

Fig. 1.

Multiple tobit regression examining the association of environmental and household characteristics on HWISE water insecurity score. Note. Betas and 95% confidence intervals shown. n = 270 households. Model additionally adjusted for income, perceived community standing, female household age, and community fixed effects. Full model available in Supplemental Table 1.

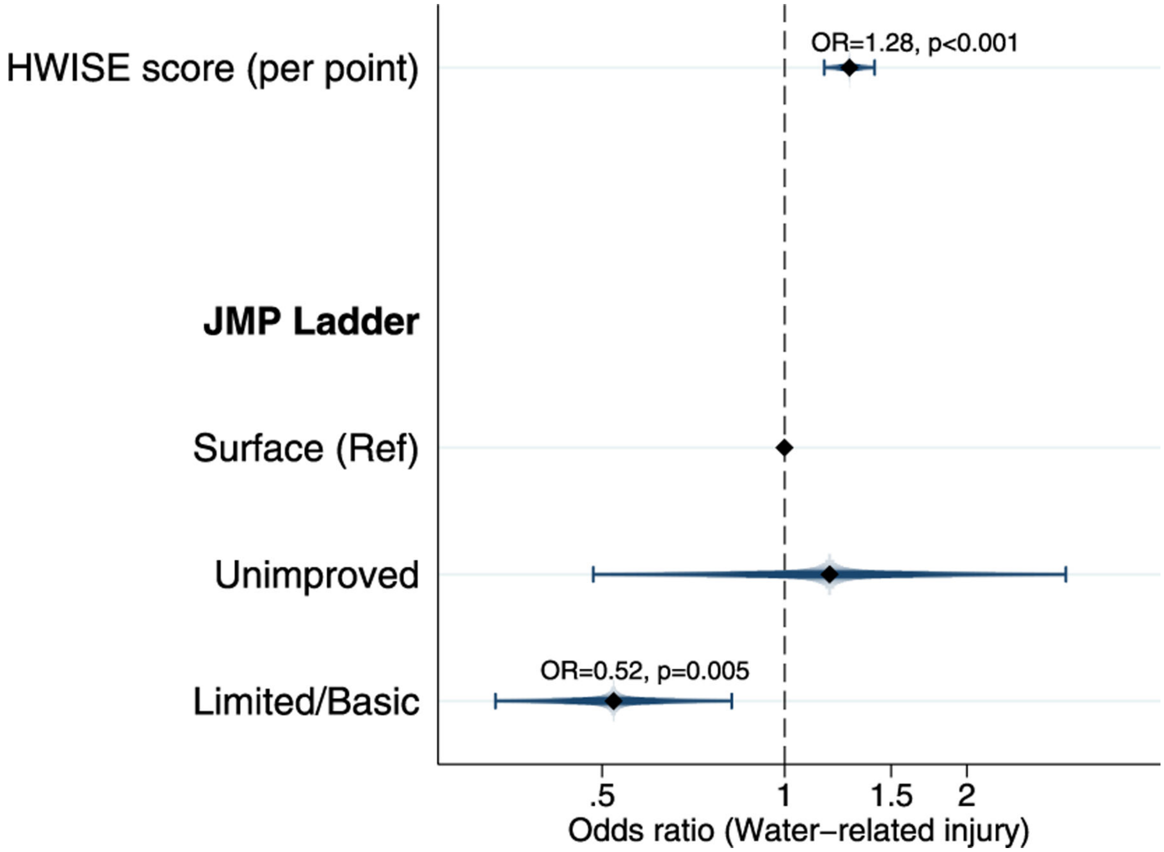

Fig. 2.

Forest plot of multiple logistic regression examining the odds ratios of water-related injury by HWISE score and JMP drinking water ladder. Note. Odds ratios and 95% confidence intervals shown. n = 270 households. Model additionally adjusted for daily water trips, HH size, HH income, perceived community standing, female household head age, and community fixed effects. Full model available in Supplemental Table 2.

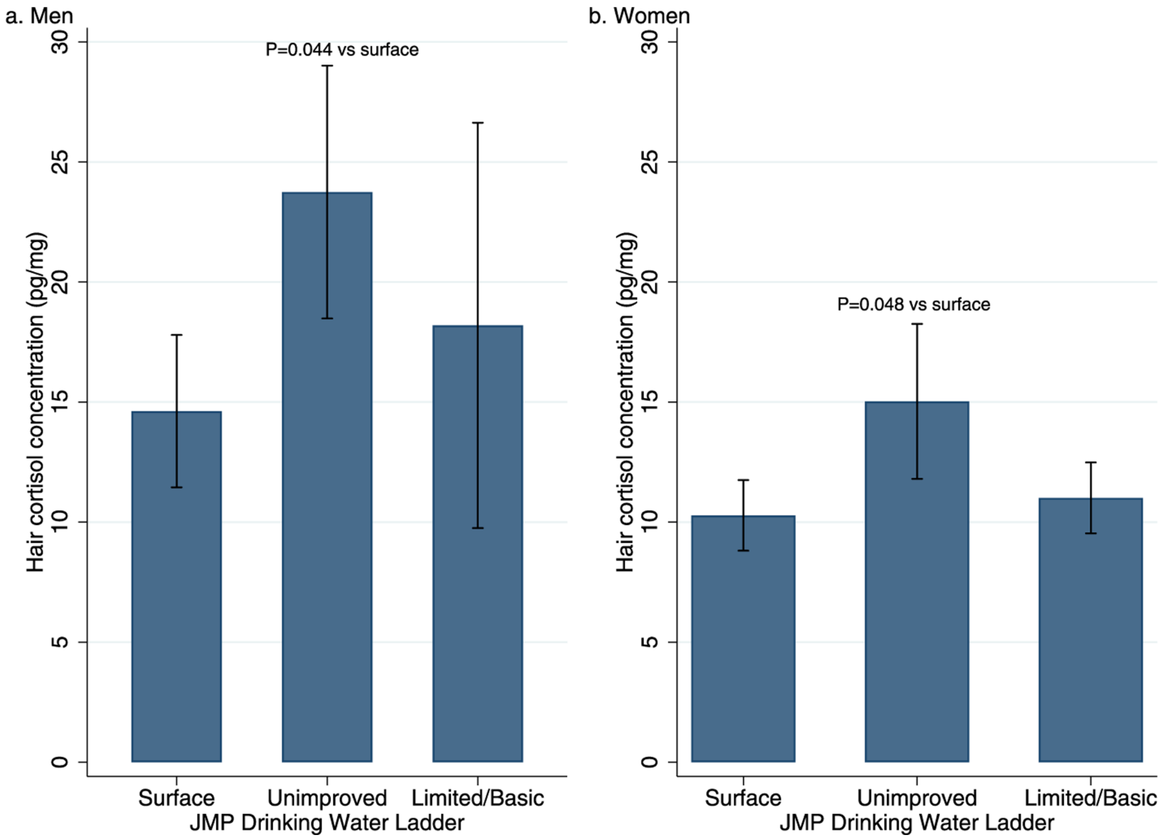

Fig. 3.

Predicted hair cortisol concentration and 95% confidence intervals by the JMP drinking water service ladder for (a) men and (b) women. Note. Built from models shown in Table 3. Model adjusted for distribution of covariates and back-transforms HCC with unbiased estimates and standard error of the variance (Huber, 2019).

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Table 1

Study sample household and individual characteristics.

HH variables	n = 270 households (HH) Mean (SD) or %
HWISE score (range 0–36)	2.2 (3.0)
Water-related injury in HH (%)	20.4%
JMP drinking water services ladder	
Surface (river, stream, pond)	23.3%
Unimproved (open well, unprotected springs)	44.8%
Limited (protected well/tap >30 min)	0.7%
Basic (protected well/tap within 30 min)	31.1%
Round-trip water fetching time (minutes)	7.0 (7.3)
Daily water fetching trips	2.3 (1.2)
Drank bad water in last 30 days	
Never (0 times)	84.4%
Rarely (1–2)	8.9%
Sometimes (3–10 times)	6.7%
Amount of drinking water stored in home (liters)	15.6 (9.9)
HH size	4.8 (2.1)
HH size adjusted for adult equivalency	4.0 (1.6)
HFIAS (range 0–27)	6.4 (4.1)
HH monthly income (bolivianos)	554.8 (817.5)
HH monthly income (natural log-transformed)	4.7 (2.7)
HH SES ranking (range 1–10, lowest to highest)	2.3 (1.4)

	Men (n = 171)	Women (n = 161)
Individual variables	**Mean (SD)**	**Mean (SD)**
Age (years)	40.5 (17.0)	38.4 (17.6)
HCC (pg/mg)	23.3 (43.8)	13.6 (20.2)
HCC (natural log-transformed)	2.5 (0.96)	2.3 (0.63)
Body fat percentage	17.4 (4.2)	26.6 (7.2)
Lactating (%)	–	41.9%

HH: household; HFIAS: household food insecurity access scale; HCC: hair cortisol concentration.

Table 2

Water quality analyses of available water sources in five Tsimane' communities.

JMP Ladder Classification:		Surface		Unimproved		Limited/Basic
	Maniqui River	Streams	Ponds	Unprotected Springs	Uncovered Wells	Protected Pump Wells
[a]Number of Sources tested	5	19	5	5	3	10
[b]Positive for fecal contamination	100%	87%	100%	40%	85.7%	44.4%
Turbidity (FNU)						
Mean (SD)	115.3 (147.8)	51.4 (80.4)	91.9 (122.6)	3.3 (4.0)	4.5 (6.0)	13.8 (28.4)
(Min, Max)	(26.9, 375.6)	(0.3, 300.5)	(1.4, 307.6)	(0, 9.8)	(0, 9.3)	(0, 93.2)
Temperature (C°)						
Mean (SD)	27.1 (3.8)	26.6 (3.1)	29.8 (3.2)	26.1 (0.8)	27.7 (1.2)	27.1 (1.7)
(Min, Max)	(21.3, 31.7)	(20.1, 32.8)	(25.4, 33.1)	(25.2, 27.4)	(26.3, 28.7)	(24.9, 31.4)
Specific Conductivity (mS/cm)						
Mean (SD)	0.1 (0.04)	0.09 (0.09)	0.1 (0.05)	0.02 (0.01)	0.2 (0.08)	0.1 (0.03)
(Min, Max)	(0.05, 0.2)	(0.02, 0.3)	(0.08, 0.2)	(0.01, 0.03)	(0.1, 0.3)	(0.04, 0.2)
Salinity (ppt)						
Mean (SD)	0.05 (0.02)	0.04 (0.04)	0.05 (0.03)	0.01 (0.01)	0.08 (0.04)	0.04 (0.02)
(Min, Max)	(0.02, 0.07)	(0.01, 0.15)	(0.03, 0.09)	(0, 0.01)	(0.05, 0.12)	(0.02, 0.08)
pH						
Mean (SD)	7.2 (0.3)	6.9 (0.5)	7.1 (0.3)	5.6 (0.5)	6.4 (0.2)	6.1 (0.3)
(Min, Max)	(6.9, 7.5)	(6.0, 7.8)	(6.6, 7.5)	(4.9, 6.4)	(6.2, 6.6)	(5.7, 6.7)

FNU: Formazin Nephelometric Unit; ppt: parts per thousand.

[a]For chemical/physiological tests, number of sources represents unique sources (for the Maniquir river it was different locations). Three measurements were taken in succession once the reading stabilized and the average was used for analyses.

[b]Some sources tested multiple times.

Table 3

OLS linear regression examining water insecurity and water access on hair cortisol concentration.

	(1)	(2)
	Men	**Women**
VARIABLES	**[a]HCC (ln)**	**[a]HCC (ln)**
	Beta (SE)	**Beta (SE)**
HWISE score (1 point)	−0.029+(0.013)	−0.012 (0.017)
Drank bad water last 30 days: never (reference)	REF	REF
1–2 times (rarely)	0.03 (0.19)	0.07 (0.21)
3–10 times (sometimes)	0.10 (0.12)	0.22+(0.092)
Anyone in HH hurt fetching water	0.21 (0.17)	0.31 * (0.09)
JMP Drinking Water Service: Surface (reference)	REF	REF
Unimproved	0.44 * (0.15)	0.38 * (0.136)
Limited/Basic	0.16 (0.30)	0.069 (0.13)
Individual’s age (year)	0.011 (0.007)	0.001 (0.003)
Body fat percentage (percentage-point)	0.002 (0.014)	0.003 (0.004)
HFIAS food insecurity score (1 point)	−0.003 (0.024)	−0.018 (0.016)
HH size adjusted for water needs	0.083 * (0.022)	0.021 (0.032)
HH Income (ln-transformed)	0.029 (0.035)	0.025 (0.028)
HH perceived community ranking (1 point higher status)	−0.063 (0.045)	0.004 (0.035)
Lactating	–	0.256+(0.071)
Observations	171	161
R-squared	0.19	0.17

Robust standard errors clustered by community in parentheses. Models adjusted for community fixed effects.

* $p < 0.05$; + $p < 0.1$.

[a]HCC: hair cortisol concentration (pg/mg) – natural log-transformed; HH: household.