Published in final edited form as:

Am J Hum Biol. 2020 January ; 32(1): e23309. doi:10.1002/ajhb.23309.

Household water insecurity is strongly associated with food insecurity: Evidence from 27 sites in low- and middle-income countries

Alexandra Brewis[1], **Cassandra Workman**[2], **Amber Wutich**[1], **Wendy Jepson**[3], **Sera Young**[4], **Household Water Insecurity Experiences – Research Coordination Network (HWISE-RCN)**

[1]Arizona State University, Tempe, Arizona

[2]University of North Carolina at Greensboro, Greensboro, North Carolina

[3]Texas A&M University, College Station, Texas

[4]Northwestern University, Evanston, Illinois

Abstract

Objectives: Food and water insecurity have both been demonstrated as acute and chronic stressors and undermine human health and development. A basic untested proposition is that they chronically coexist, and that household water insecurity is a fundamental driver of household food insecurity.

Methods: We provide a preliminary assessment of their association using cross-sectional data from 27 sites with highly diverse forms of water insecurity in 21 low- and middle-income countries across Africa, Asia, the Middle East, and the Americas (N = 6691 households). Household food insecurity and its subdomains (food quantity, food quality, and anxiety around food) were estimated using the Household Food Insecurity Access Scale; water insecurity and subdomains (quantity, quality, and opportunity costs) were estimated based on similar self-reported data.

Results: In multilevel generalized linear mixed-effect modeling (GLMM), composite water insecurity scores were associated with higher scores for all subdomains of food insecurity. Rural households were better buffered against water insecurity effects on food quantity and urban ones

---

Correspondence Alexandra Brewis, Arizona State University, Tempe, Arizona. alex.brewis@asu.edu.

AUTHOR CONTRIBUTIONS

A.W., W.J., and S.L.Y. designed the data collection; all authors were engaged in either data collection or core data management for one or more sites; S.L.Y. oversaw initial data integration; A.B., C.W., A.W., and S.L.Y. theorized the analysis; A.B. designed and conducted the analysis; A.B. drafted the manuscript with assistance from C.W., A.W., W.J., and S.L.Y. All authors critically reviewed the final manuscript.

HWISE-RCN coauthors: Ellis Adams, Jam Farooq Ahmed, Mallika Alexander, Mobolanle Balogun, Michael Boivin, Genny Carrillo, Kelly Chapman, Stroma Cole, Shalean Collins, Luisa Figueroa, Matthew Freeman, Asiki Gershim, Hala Ghattas, Ashley Hagaman, Zeina Jamaluddine, Wendy Jepson, Desire Tshala-Katumbay, Divya Krishnakumar, Kenneth Maes, Jyoti Mathad, Jonathan Maupin, Patrick Mbullo, Joshua Miller, Ica Martin Muslin, Monet Niesluchowski, Nasrin Omidvar, Amber Pearson, Hugo Melgar-Quiñonez, Cuauhtemoc Sanchez-Rodríguez, Asher Rosinger, Marianne Vicky Santoso, Roseanne Schuster, Sonali Srivastava, Chad Staddon, Justin Stoler, Andrea Sullivan, Yihenew Tesfaye, Nathaly Triviño, Alex Trowell, Raymond Tutu, Jorge Escobar-Vargar, Hassan Zinab.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

for food quality. Similarly, higher scores for all subdomains of water insecurity were associated with greater household food insecurity.

Conclusions: Considering the diversity of sites included in the modeling, the patterning supports a basic theory: household water insecurity chronically coexists with household food insecurity. Water insecurity is a more plausible driver of food insecurity than the converse. These findings directly challenge development practices in which household food security interventions are often enacted discretely from water security ones.

1 | INTRODUCTION

Biocultural research has demonstrated that both household food and water insecurity are associated with greater stress and worse developmental, physical, and mental health outcomes (Boateng et al., 2018; Boateng et al., n.d.; Collins et al., 2019; Krumdieck et al., 2016; Wutich, Brewis, Chavez, & Jaiswal, 2016, Stevenson et al., 2012; Workman & Ureksoy, 2017; Wutich, 2009; Wutich & Ragsdale, 2008, Wutich & Brewis, 2014, Weaver & Hadley, 2009). It is likely that the deleterious effects of food and water insecurity on human biological outcomes are multiplicative. For example, a recent population representative analysis of 8633 Nepali women showed that those in households with both food and water insecurity had the highest blood pressure, a commonly applied indicator of physiological stress (Brewis, Choudhary, & Wutich, 2019). Similarly, in three economically vulnerable communities in Haiti, adults in 4055 households characterized by both food and water insecurity had more symptoms of depression and anxiety than households with just food or water insecurity (Brewis et al., 2019).

Theorizing and then establishing with precision the relationship(s) between household water and food insecurity is critical for basic theory and also for the informing developmental practice. Water insecurity is an increasing global challenge associated not just with climate change but also with ongoing institutional, infrastructural, and policy failures (Cole, 2017; Rockström et al., 2009; Swyngedouw, 2013; Vörösmarty et al., 2010). And, if water insecurity proves to be a significant driver of food insecurity at the household level, this has major implications for identifying key proximate factors that shape health and human biological variation, as well as the design of more effective nutrition and other related poverty interventions. Currently, many global efforts toward household-level poverty alleviation focus more on bolstering food and nutrition security than on the improvement of water security (WHO 2018)—although this is starting to change (Ringler et al., 2018).

Our goal herein is to test hypotheses relevant to basic theory building around the ways by which food and water insecurity might relate to each other at a household scale. We begin by reviewing the prior literature that has considered empirically the proximate theorized connections between household water and food insecurity. We then integrate and model cross-sectional data collected from households within 27 highly ecologically diverse urban and rural community sites in Africa, Asia, the Middle East, and the Americas, all with known problems with water (Young et al., 2018). A significant advantage of the data set used herein is the application of consistent measures of both food and water insecurity at a single scale (the household) across multiple sites. Indeed, biocultural scholars have also noted the difficulty in parsing out the relative—let alone exacerbating—effects of food and water insecurity on people living with them due to a dearth of studies that concurrently measure both food and water insecurity, or operationalize the concepts quite differently (eg, Wutich & Brewis, 2014; Stevenson et al., 2012; Workman & Ureksoy, 2017; see Jepson, Wutich, Colllins, Boateng, & Young, 2017 and Wutich & Brewis, 2014 for a discussion of this as a broader challenge).

Our general predictions are as follows:

1. Total household water insecurity will be consistently and positively significantly associated with total household food insecurity.
2. Subdomains of household food insecurity operationalized as (a) less quantity of food, (b) worse quality of food, and (c) more worry around food will all consistently be associated with higher (worse) household water insecurity scores.
3. Subdomains of household water insecurity operationalized as (a) lesser quantity of water, (b) worse perceived quality of water, and (c) greater time/labor costs of managing water will be consistently associated with higher (worse) household food insecurity scores.

Here, we are considering empirically some of the likely numerous mechanisms that could proximately connect food insecurity and water insecurity *within households*, as a locus where both food and water can have profound impacts on human biological variation and its associated health risks (Wutich, 2020, in this issue). By the household, we mean the minimum cooperative social and economic unit of people, that is, those who “share a pot” at mealtimes and are normally coresident (Netting, Wilk, & Arnould, 1984). We note there is a parallel literature linking the aspects of community-level water availability and food factors like price (eg, Bacon, Sundstrom, Stewart, & Beezer, 2017; Grace, Brown, & McNally, 2014; McCordic & Abrahamo, 2019), but it is at a different scale, and therefore outside the scope of what we are exploring.

2 | HOW MIGHT HOUSEHOLD WATER INSECURITY EXACERBATE FOOD INSECURITY?

2.1 | First, water insecurity could result in worsening food insecurity because it inhibits the ability of households to produce food for their own consumption, or to generate income that can be used to purchase food, or the ability to switch between the two

House gardens or plots require sufficient water, thus household water insecurity may reduce the benefits of agricultural activities on mitigating food insecurity (Tesfamariam, Owusu-Sekyere, Emmanuel, & Elizabeth, 2018; Whitney et al., 2018). For example, based on surveys in 120 households across Kenya, Tanzania, and Uganda, food insecurity was mostly profound in the zones of <700 mm annual rainfall; the implied mechanism has reduced crop yields and failures (Rufino et al., 2013). Pakistani farm households with relative water scarcity had a lower cereal crop yield and income, and were therefore more food insecure (N = 950) (Rahut, Ali, Imtiaz, Mottaleb, & Erenstein, 2016). In South Africa, a study of highly water-secure smallholder farmers (N = 185) showed they were twice as productive in the agricultural output as those who were water insecure because they could better irrigate (Sinyolo, Mudhara, & Wale, 2014). The shock of unexpected water can also negatively impact household agricultural production. In Lowland Bolivia, for example, almost all of 62 horticulturalist households surveyed following an historic flood loss of some or all of their crops, impacting their food insecurity long afterward (Rosinger, 2018).

Additionally, animals are an important source of protein and calories and serve as a source of assets that buffer against shocks to the household economy; animals are therefore integral to household food security, particularly in rural areas of lower income countries (Dumas et al., 2018; Freeman, Kaitibie, Moyo, & Perry, 2008; Reynolds, Wulster-Radcliffe, Aaron, & Davis, 2015). Animals, however, require water directly and indirectly through their feed requirements. A small study in Peru, for example, has shown the sensitivity of Alpaca herder families (N = 30) to alterations in water availability (Verzijl & Quispe, 2013). There is also a general, if vague, suggestion that raising poultry may sometimes be preferred to other animals where water is limited *because* they need comparatively little water (Kitalyi, 1998; Mwalusanya et al., 2002).

2.2 | Water insecurity may also limit food choices by acting as a constraint on household food preparation and what can be eaten

For example, pregnant and postpartum Kenyan women (N = 371) reported the change in foods being cooked and served to families as a consequence of water insecurity (Collins et al., 2017). Beans, for example, which are a cheap and nutritious food, require much more water to cook than does less nutritious and more expensive rice or pasta. In an arid informal settlement in Bolivia, women reported that water insecurity limited cooking; one respondent reported “one day the water ran out and I could not cook” (Wutich, 2009). Workman and Ureksoy (2017) similarly found that water scarcity affected food preparation in rural Lesotho as they were told, “you can't cook the food if you don't have the water.” We expect that this mechanism would particularly impact food quality (eg, ability to eat preferred foods) although it could also undermine total food quantity as well.

2.3 | The need to purchase and treat water can directly undermine household income and food budget

Buying water can be a major financial stress on households. Treatment of water to make it safe to drink (eg, with chlorine tablets, boiling it) also costs money, diverting available cash from the household food budget. Households in lower income countries spend a disproportionate amount of their income on water provisioning, particularly when they have to rely on water vendors or informal water markets (Water Aid, 2016). In the aforementioned study in rural western Kenya, household money meant to be used for food was sometimes diverted to purchase water (Collins et al., 2019). Similarly, 40 interviewees in Mumbai, India, suggested that the household money for food was sometimes reallocated to purchase water (Subbaraman et al., 2015). Moreover, some Mumbai respondents reported that they would miss work or leave work early to procure water, directly reducing household budgets for food. In Labuan Bajo, Indonesia, Cole (2017) found that how several women reported waiting for water as a major impediment to their participation in the labor force.

2.4 | Effort spent on water acquisition activities undermines household capacity to mitigate food insecurity

In much of the world, women are the primary household water managers (Cole & Ferguson, 2015; Sultana & Loftus, 2012), just as they are often the primary preparers of food (Wutich & Brewis, 2014). A recent meta-analysis of 42 studies found that there is moderate quantitative evidence and strong qualitative evidence to demonstrate that carrying water heightens fatigue and other physical ailments (Geere et al., 2018; Geere, Cortobius, Geere, Hammer, & Hunter, 2018). Many households that access off-plot water require women and girls to negotiate water source access, walk to public sources, transfer water into containers, and carry it to their homes for use and storage. This can be a very time consuming, physically demanding, and sometimes dangerous task (eg, falls, sexual assault). The farther the water sources are from the household, the greater the burden.

Furthermore, the time spent fetching water or recovering from water-related physical harm cannot be spent doing other food-relevant productive activities, such as planting, weeding, harvesting crops, caring for animals, collecting fuel for cooking, preparing food, or feeding children. For example, the same Mumbai women reported that the time spent fetching water impinged on their time to complete household chores and childcare (Subbaraman et al., 2015). Kenyan women stated that water-fetching tasks meant inadequate time to prepare foods for children and also inhibited their incomegenerating activities (Collins et al., 2019). In Tanzania, women spending more time in water collection had lower labor productivity (such as in farming and gardening) and lower crop yields (Allen, Qaim, & Temu, 2013). There are most likely longer-term deleterious relationships between food and water insecurity linked to these constraints, such as being late to school, missing school periodically, or being taken out of school entirely.

2.5 | Water insecurity can also render otherwise nutritious foods unsafe

Washing, soaking, or boiling food, and washing utensils and food preparation surfaces remove pathogens and toxins, thereby making foods safe to eat. Lack of water may thus curtail dietary options in households; it could be especially deleterious to young children, who are more reliant on specially prepared foods that are safely digestible (eg, boiled longer, prepared with clean water) to meet their nutritional needs (eg, Schuster et al., 2020, in this issue). For example, in one study of 140 households in Bangladesh, 40% of young child feeding stocks were contaminated with *Escherichia coli* because of reliance on low-quality water (Islam et al., 2012). Contaminated water may also render household crops or local wild foods unsafe to eat. For example, Schell (2020) describes how industrial pollutants on Akwesasne Mohawk nation lands led to locally fished and gathered wild foods being declared unsafe for consumption, narrowing nutritious food options for households within the contamination zones.

3 | HOW MIGHT HOUSEHOLD FOOD INSECURITY EXACERBATE WATER INSECURITY?

Overall, the evidence of household food insecurity as a potential driver for water insecurity is minimal compared to the converse. We can, however, identify at least three possible candidate mechanisms by which food insecurity could shape water insecurity.

3.1 | Water collection requires physical energy

Inadequate food intake then could impact a household's energetic capacity to procure water, especially if water sources are distant. A small (N = 37) study in Laos found that mean energy expenditure was 4.2% of the average daily caloric requirement in the dry season and rose to 5.5% in the rainy season because of the additional energetic burden of navigating muddy roads while balancing heavy loads of water (La Frenierre, 2017). Households located at the greatest distance from water sources expended the most energy.

3.2 | When preferred foods are scarce, households may become more reliant on foods that require more time or water to prepare

Bitter cassava, for example, requires a significant amount of soaking time to remove toxins (Dufour, 1994). Additional time required to acquire or process “famine foods” (such as collecting wild food) cannot then be allocated to improving the household water situation.

3.3 | Decisions to prioritize purchases of food or investments in food production may exacerbate water insecurity

This could occur by diverting money from purchasing water, from materials for water treatment, or from investing in other water infrastructure for the household, for example, storage containers, thereby in turn increasing household water insecurity.

On this basis, it seems likely that household water insecurity will more consistently predict household food insecurity rather than the other way around. That is, water is required for almost every aspect of household food production, management, and preparation, but the converse is not the case. Indeed, household food security is not possible without adequate water, unless households are always able to buy all food fully prepared.

4 | METHODS

4.1 | Data sources: The HWISE study

Data obtained from the Household Water Insecurity Experiences (HWISE) study conducted between March 2017 and July 2018 consisted of households from 27 sites in 21 low- and middle-income countries (Figure 1) (Young et al., 2018). The HWISE study sites were selected in order to capture a wide array of ecologies in which water insecurity occurs, from urban settings where insecurity is based on market failures or weak infrastructure, to highly arid seasonal subsistence communities primarily dependent on surface water. For 816 of the 7507 households, one or more of the key variables or covariates were missing, thus providing a final analytic sample of 6691. The exact method for selection of surveyed households varied by site, as did the seasons of data collection (Table 1, see also Young et al., 2018). The sample sizes varied somewhat across sites, but were collected with the target of 250 households in each. An adult member who identified themselves as knowledgeable about the household water was interviewed in each household (72.1% women). Informed consent procedures at each site followed the protocols approved by the site PI's (Principal Investigator) home institution(s).

4.2 | Key variables

4.2.1 | Household water insecurity—We operationalized household water insecurity in several ways. We began by selecting 14 water-related survey items from the longer HWISE study surveys presented in Young et al. (2018) relevant to four subdomains of theoretical interest. These were (a) insufficient water quantity (based on 7 items related to the impacts of water shortages), (b) low water quality (2 items), (c) time/labor costs of water insecurity (3 items), and (d) the reported impact of water insecurity on changing what was eaten (1 item) (see Table 2). The time/labor items included “time to fetch water” recorded as minutes and then converted to a three-level variable due to skewness of distribution. For the other questions, the period of recall was the prior 4 weeks, and the Likert-type responses were individually scored as: 0 = never or not applicable, 1 = rarely (1-2 times), 2 = sometimes (3-10 times), 3 = often (11-20 times), or 4 = always (>20 times). Subdomain items were then converted to single variables through principal component analysis (PCA) (see Table 2). In all cases, only one single dimension was extracted, explaining 54.1% of variation in water quantity, 85.7% in water quality, and 53.7% of time/labor. Changes in food eaten had only a single item in that domain and were thus analyzed based on its original 0-4 score.

We also created a total household water insecurity score by summing the 12 Likert-type response items (ie, not including “time to fetch water and return”), such that the potential range was 0-48, with higher scores suggesting greater water insecurity. (This is procedurally similar to how the Household Food Insecurity Access Scale [HFIAS] food insecurity scores are generated.) We tested the internal reliability of this constructed 12-item unidimensional total household water insecurity score and found that Cronbach's alpha was high (*kappa* = .898). The convergent validity of this summary score was then assessed against the cross-culturally validated 12-item HWISE scale (Young et al., n.d.), using bivariate regression on the 12 sites for which the full set of items required to calculate HWISE scale scores was available. Correlation was very high ($B = 0.903$, SE = 0.005, $P < .001$; correlation coefficient = 0.955, $N = 2082$), suggesting that the two measures similarly capture some heuristic of household water insecurity.

4.2.2 | Household food insecurity—Household food insecurity was assessed using the HFIAS study (Coates, Swindale, & Bilinsky, 2007). HFIAS scores were derived based on survey answers to nine Likert-type questions of frequency of food insecurity in the prior 4 weeks scored 0-3, summed to a total ranging from 0 to 27 (higher scores suggesting more insecurity). If respondents were missing only in one of nine HFIAS items, then that item was imputed with the item mean for that site (see Bickel, Nord, Price, Hamilton, & Cook, 2000 for justification). Other cases of missingness were removed from analyses.

Food insecurity subdomains were operationalized as single variables using the summation procedures already established and widely applied in HFIAS analyses (Coates et al., 2007:6). These domains are (a) insufficient quantity of food intake and related physical consequences (based on five items, ranging 0-15), (b) insufficient quality including variety and preferences for food (based on summation of three items, with a possible range of 0-9), and (c) anxiety and uncertainty about household food supply (based on response to a single question item, ranging 0-3).

4.2.3 | Other covariates—Some sites were fully rural, others fully urban or peri-urban, and some were a mix of rural and nonrural households (see Young et al., 2018; Table 2); the variable representing rurality was coded at the household level as rural (1) or not (0). We created the variable as binary because there were slight differences across sites in how peri-urban and urban designations were applied. We operationalized socioeconomic status using the MacArthur scale of Subjective Social Status (Adler et al., 2008). For this, respondents are shown a picture of a ladder representing the socioeconomic status of people in their community and asked to select the rung that best represents their own status. The top rung of the ladder represents those best off (scored as 10); the bottom rung represents those who are the worst off (score of 1). We also considered whether data were collected in the dry season or not; this had no apparent influence on the outcome variables once all the key variables and other covariates were considered, and so was removed from the final models.

4.3 | Statistical analysis

Our general approach to testing predictions from the combined data set was a nested multivariate analysis that treated the study site as a random effect. To test our hypothesis that the water insecurity summary score is positively associated with total household food insecurity and its subdomain scores, we used generalized linear mixed-effect modeling (GLMM), conducted in R version 3.5.1 (R core team, 2008) using the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015) and the *glm* function, which assumes a Gaussian distribution. This approach was preferred because it could manage unbalanced sample sizes across sites, was suited to the number of sites at the second level (Meuleman & Billiet, 2009, and did not assume that sites were drawn from some larger samples. Model 0 contained the terms of the full model, except for the key independent variables. We conducted model comparisons using likelihood ratio tests. Model coefficients were then used as the primary basis for establishing the significance of the tests, but *P* values are also provided for the interpretability of results.

5 | RESULTS

Total household water insecurity scores ranged from a low mean of 1.47 (SD = 4.2) in Pune, India, to a high mean of 24.61 (SD = 7.3) in Punjab, Pakistan. Mean food insecurity scores were also highly variable across sites, ranging from a mean of 1.03 (SD = 2.6) in Kathmandu, Nepal, to 16.2 (SD = 4.9) in Kahemba, DRC. As per our first hypothesis, the bivariate correlations between household food and water summary scores were positive across all the sites (Figure 2). The site-specific regressions predicting food insecurity by water insecurity scores were also highly significant ($P < .001$), except in Acatenango, Guatemala ($P = .050$; notably the smallest sample at N = 101), Punjab, Pakistan ($P = .053$; the least water secure site), and Pune, India ($P = .088$; the most water secure and also one of the most food secure sites).

The relationships between total household water insecurity score and total HFIAS food insecurity scores (Model 1) are presented with Model 0 (lacking key predictors) for comparison in Table 3. The relationships between the scores of the water insecurity subdomains (quality, quantity, and time/labor impacts) and food insecurity, as well as between rural residence and perceived social status (Model 2), are also shown. In this and the following models, all the water insecurity variables exhibited very low SE values, suggesting a model precision.

In Models 1 and 2 (Table 3), a lower perceived social status was significantly associated with greater food insecurity summary scores, whereas rural residence was not. In Model 1, total household water insecurity scores were strongly significantly associated with total household food insecurity (estimate = 0.330, $P < .001$). In other words, as household water insecurity worsened, food insecurity also worsened; urban and rural households were similarly affected. The three water subdomains (all $P < .001$) were strongly associated with overall HFIAS scores as shown in Model 2, with worse water quantity having the strongest association (coefficient = 1.809) followed by time/labor impacts (1.146) and worse water quality (0.460). That is, better water quantity, water quality, and reduced time spent on water management were all associated with a greater household food security.

We then tested the relationship between total water insecurity scores and the food insecurity subdomain scores, that is, quantity, quality, and food-related anxiety (Models 3-5; Table 4). Worse (ie, higher) total household water insecurity scores had an additional significant effect on worsening food quantity scores (estimate = 0.169, $P < .001$). That is, as water insecurity increased, the quantity of food available to the household decreased. Higher total household water insecurity scores were also positively associated with reduced food quality (Table 4, Model 4; estimate = 0.042, $P < .001$). That is, as water insecurity of the household worsened, so did the quality of household food. We also found that as water insecurity worsened, so did worry around food (estimate = 0.084, $P < .001$). Rural residency reduced the effects of water insecurity on worsening food quantity (estimate = −5.316, $P < .001$) and food-related anxiety (−7.621, $P < .001$); however, it increased the reports of issues with food quality (estimate = 3.216, $P < .001$). Higher social status was associated with reduced effects of water insecurity on food quantity and quality (estimates of 22.044 and 20.926, respectively, both $P < .001$), but not on food-related anxiety ($P > .1$).

We then explored the relationship between total household water insecurity scores and the frequency of households changing what was cooked or eaten because of water issues (Table 4, Model 6). Households with more water insecurity were more likely to report changing what was eaten (estimate = 0.08, $P < .0001$). Water insecurity had more of an effect on changing what was eaten in urban/peri-urban compared to rural households.

6 | DISCUSSION

After theorizing potentially influential relationships between household food and water insecurity, we used data from 27 sites in 21 lower- and middle-income countries to examine cross-sectional associations. Consistent with our first prediction, we found that household water insecurity was consistently positively associated with household food insecurity (Table 3). When we modeled the relationships between subdomains of household water insecurity (lower water quantity, worse quality, and more time/labor impacts) with food insecurity, we also found that each was independently associated with worsening household food insecurity measures (Table 4). The greatest single effect of worsening food insecurity was from increased water scarcity.

Of course, establishing directionality will be crucial to better theorizing how food and water insecurity matter to each other. Given a cross-sectional design, we cannot establish causality. Also, in particular, our variable of water quality may not well capture that domain as it is based solely on two questions of perceived safety and taste. An obvious next step to clarifying the causative influence of water insecurity on food insecurity is to conduct detailed, household-focused, longitudinal studies examining more directly the complex, real-time (eg, seasonal) trade-offs that people are making around valuable household resources (food, water, assets, and labor). Future studies should also endeavor to apply better measures of water quality.

The apparent effects of water insecurity on food security were—perhaps not surprisingly—found to be generally worse for lower status households. This is consistent with a substantial literature identifying water insecurity as being highly associated with—perhaps even definitional of—extreme material poverty (Wutich & Brewis, 2014). In terms of rural vs urban households, the initial models showed no locational differences in effect of water insecurity on total household food insecurity scores. However, when we examined the effect of water insecurity on the subdomains of food insecurity, some interesting patterns emerged. Rural households, as would be expected given their greater capacity to directly produce food, appear to be better buffered against the effects of water insecurity on worsening food quantity, anxiety, and the need to change what was eaten. Urban households appear to be better buffered against the effects of water insecurity on worsening household food quality. As the designations of households as peri-urban were, as noted, somewhat inconsistent across sites, this must be considered a tentative suggestion. We also caution that this preliminary analysis does not take into account drought impacts that would likely eliminate any such buffering.

Despite these limitations, our findings nonetheless reveal the importance of developing and testing theoretical models that consider how urban vs rural contexts differently shape household food water dynamics, and the likely differing consequences these have for human health and biology. For example, we can hypothesize that urban households are likely to have more available diverse food options and flexibility, compared to how water insecurity would otherwise limit food choices and act as a constraint on food preparation and what can be eaten in rural areas. Although dietary diversity varies among urban households, especially between formal and informal residents (Drimie, Faber, Vearey, & Nunez, 2013), we know that urban food systems are generally less limited by seasonality and can draw on a wider array of food types and sources, including highly processed and packaged foods. Urban food systems also integrate production from local to international agricultural production to provide diverse fresh options at market (Maxwell, 1999; Crush & Frayne, 2011). Thus, urban households typically may have more options, depending on their purchasing power, in response to the constraints on food created by water insecurity than rural counterparts (Battersby, 2011).

In summary, these cross-sectional models clearly and consistently demonstrate that as household water quantity and quality decrease and/or time allocated to water management increases, food insecurity increases. Households also reported that they are forced to change what they are eating because of problems with water. These findings, responding to a recent call for better evidence for basic theory building (Wutich & Brewis, 2014), add significantly to what we know about the fundamental relationships between household food and water insecurity. By considering the effects across 27 very diverse community sites in 21 countries, we conclude that we are observing what is likely a broad-scale and important pattern: both quantity *and* quality of household water appear to significantly shape all major dimensions of household food insecurity.

ACKNOWLEDGMENTS

This project was funded by the Competitive Research Grants to Develop Innovative Methods and Metrics for Agriculture and Nutrition Actions (IMMANA). IMMANA is funded with UK Aid from the UK government. The overall project was also supported by the Buffett Institute for Global Studies and the Center for Water Research at Northwestern University; Arizona State University's Center for Global Health at the School of Human Evolution and Social Change and Decision Center for a Desert City (National Science Foundation SES-1462086); the Office of the Vice Provost for Research of the University of Miami; the National Institutes of Health grant NIEHS/FIC R01ES019841 for Kahemba; Lloyd's Register Foundation for Labuan Bajo, and SHHD and SSRI at Penn State University for San Borja. We are very grateful to the field teams, including enumerators, identified in Young et al. (2018).

Funding information

Competitive Research Grants to Develop Innovative Methods and Metrics for Agriculture and Nutrition Actions (IMMANA); National Institute of Environmental Health Sciences, Grant/Award Number: R01ES019841; National Science Foundation, Grant/Award Number: SES-1462086

REFERENCES

Adler N, Singh-Manoux A, Schwartz J, Stewart J, Matthews K, & Marmot MG (2008). Social status and health: A comparison of British civil servants in Whitehall-II with European- and African-Americans in CARDIA. Social Science & Medicine, 66(5), 1034–1045. [PubMed: 18180089]

Allen S, Qaim M, & Temu A (2013). Household water constraints and agricultural labour productivity in Tanzania. Water Policy, 15 (5), 761–776.

Bacon CM, Sundstrom WA, Stewart IT, & Beezer D (2017). Vulnerability to cumulative hazards: Coping with the coffee leaf rust outbreak, drought, and food insecurity in Nicaragua. World Development, 93, 136–152.

Bates D, Maechler M, Bolker B, & Walker S (2015). Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67(1), 1–48. 10.18637/jss.v067.i01

Battersby J (2011). Urban food insecurity in Cape Town, South Africa: An alternative approach to food access. Development Southern Africa, 28(4), 545–561.

Bickel G, Nord M, Price C, Hamilton W, & Cook J (2000). Guide to measuring household food security, revised (p. 2000). Alexandria VA: U.S. Department of Agriculture, Food and Nutrition Service.

Boateng GO, Collins SM, Mbullo P, Wekesa P, Onono M, Neilands TB, & Young SL (2018). A novel household water insecurity scale: Procedures and psychometric analysis among postpartum women in western Kenya. PLoS One, 13(6), e0198591. [PubMed: 29883462]

Boateng G, Workman CL, Miller JD, Onono M, Neilands TB, & Young SL. (n.d.) "The syndemic effects of food insecurity, water insecurity, and HIV on maternal depression among a Kenyan cohort"

Brewis A, Choudhary N, & Wutich A (2019). Low water access as a gendered physiological stressor: Blood pressure evidence from Nepal. American Journal of Human Biology, 31, e23234. [PubMed: 30900309]

Coates J, Swindale A, & Bilinsky P (2007). Household food insecurity access scale (HFIAS) for measurement of food access: Indicator guide, version 3. In Food and nutrition technical assistance project. Academy for educational development. USAID Washington, DC.

Cole S (2017). Water worries: An intersectional feminist political ecology of tourism and water in Labuan Bajo, Indonesia. Annals of Tourism Research, 67, 14–24.

Cole S, & Ferguson L (2015). Towards a gendered political economy of tourism and water. Tourism Geographies, 17(4), 511–528.

Collins SM, Mbullo Owuor P, Miller JD, Boateng GO, Wekesa P, Onono M, & Young SL (2019). 'I know how stressful it is to lack water!' Exploring the lived experiences of household water insecurity among pregnant and postpartum women in western Kenya. Global Public Health, 14(5), 649–662. [PubMed: 30231793]

Collins SM, Miller JD, Mbullo P, Boateng GO, Wekesa P, Onono M, & Young SL (2017). "You take the cash meant for beans and you buy water": The multi-faceted consequences of water insecurity for pregnant and postpartum Kenyan women of mixed HIV status. The FASEB Journal, 31(1), 651–654.

Crush J, & Frayne B (2011). Supermarket expansion and the urban food economy in southern African cities: Implications for urban food security. Journal of Southern African Studies, 37(4), 781–807.

Drimie S, Faber M, Vearey J, & Nunez L (2013). Dietary diversity of formal and informal residents in Johannesburg, South Africa. BMC Public Health, 13(1), 911. [PubMed: 24088249]

Dufour DL (1994). Cassava in Amazonia: Lessons in utilization and safety from native peoples. In International workshop on cassava safety. Acta Hortic, 375, 175–182.

Dumas SE, Maranga A, Mbullo P, Collins S, Wekesa P, Onono M, & Young SL (2018). "Men are in front at eating time, but not when it comes to rearing the chicken": Unpacking the gendered benefits and costs of livestock ownership in Kenya. Food and Nutrition Bulletin, 39(1), 3–27. 10.1177/0379572117737428 [PubMed: 29226708]

Freeman A, Kaitibie S, Moyo S, & Perry B (2008). Livestock, livelihoods and vulnerability in selected SADC countries (Lesotho, Malawi and Zambia). International Livestock Research Institute (ILRI) Research Report, 8.

Geere JA, Bartram J, Bates L, Danquah L, Evans B, Fisher MB, … Nguyen-Viet H (2018). Carrying water may be a major contributor to disability from musculoskeletal disorders in low income countries: A cross-sectional survey in South Africa, Ghana and Vietnam. Journal of Global Health, 8(1), 010406. [PubMed: 29497503]

Geere JAL, Cortobius M, Geere JH, Hammer CC, & Hunter PR (2018). Is water carriage associated with the water carrier's health? A systematic review of quantitative and qualitative evidence. BMJ Global Health, 3(3), e000764.

Grace K, Brown M, & McNally A (2014). Examining the link between food prices and food insecurity: A multi-level analysis of maize price and birthweight in Kenya. Food Policy, 46, 56–65.

Islam MA, Ahmed T, Faruque ASG, Rahman S, Das SK, Ahmed D, … Cravioto A (2012). Microbiological quality of complementary foods and its association with diarrhoeal morbidity and nutritional status of Bangladeshi children. European Journal of Clinical Nutrition, 66(11), 1242–1246. [PubMed: 22805495]

Jepson WE, Wutich A, Colllins SM, Boateng GO, & Young SL (2017). Progress in household water insecurity metrics: A cross-disciplinary approach. Wiley Interdisciplinary Reviews: Water, 4(3), e1214.

Kitalyi AJ (1998). Village chicken production systems in rural Africa: Household food security and gender issues (No. 142). Food & Agriculture Organization (FAO) Animal Production and Health Paper 142.

Krumdieck NR, Collins SM, Wekesa P, Mbullo P, Boateng GO, Onono M, & Young SL (2016). Household water insecurity is associated with a range of negative consequences among pregnant Kenyan women of mixed HIV status. Journal of Water and Health, 14(6), 1028–1031. [PubMed: 27959881]

La Frenierre J (2017). Caloric expenditure as an indicator of access to water. wH2O: The Journal of Gender and Water, 5(1), 3.

Maxwell D (1999). The political economy of urban food security in sub-Saharan Africa. World Development, 27(11), 1939–1953.

McCordic C, & Abrahamo E (2019). Family structure and severe food insecurity in Maputo and Matola, Mozambique. Sustainability, 11(1), 267.

Meuleman B, & Billiet J (2009). A Monte Carlo sample size study: How many countries are needed for accurate multilevel SEM? Survey Research Methods, 3(1), 45–58.

Mwalusanya NA, Katule AM, Mutayoba SK, Mtambo MMA, Olsen JE, & Minga UM (2002). Productivity of local chickens under village management conditions. Tropical Animal Health and Production, 34(5), 405–416. [PubMed: 12379059]

Netting RM, Wilk RR, & Arnould EJ (Eds.). (1984). Households: Comparative and historical studies of the domestic group (Vol. 324). Berkeley: University of California Press.

Rahut DB, Ali A, Imtiaz M, Mottaleb KA, & Erenstein O (2016). Impact of irrigation water scarcity on rural household food security and income in Pakistan. Water Science and Technology: Water Supply, 16(3), 675–683.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Reynolds LP, Wulster-Radcliffe MC, Aaron DK, & Davis TA (2015). Importance of animals in agricultural sustainability and food security. The Journal of Nutrition, 145(7), 1377–1379. [PubMed: 25972529]

Ringler C, Choufani J, Chase C, McCartney M, Mateo-Sagasta J, Mekonnen D, & Dickens C 2018. Meeting the nutrition and water targets of the Sustainable Development Goals: Achieving progress through linked interventions. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE); Washington, DC, USA: The World Bank. 24p. (WLE Research for Development (R4D) Learning Series 7). doi: 10.5337/2018.221.

Rockström J, Steffen W, Noone K, Persson Å, Chapin FS III, Lambin EF, … Nykvist B (2009). A safe operating space for humanity. Nature, 461(7263), 472–475. [PubMed: 19779433]

Rosinger AY (2018). Household water insecurity after a historic flood: Diarrhea and dehydration in the Bolivian Amazon. Social Science & Medicine, 197, 192–202. [PubMed: 29253721]

Rufino MC, Thornton PK, Mutie I, Jones P, Van Wijk M, & Herrero M (2013). Transitions in agro-pastoralist systems of East Africa: Impacts on food security and poverty. Agriculture, Ecosystems & Environment, 179, 215–230.

Schell L (2020). In this issue.

Schuster R et al. (2020). In this issue.

Sinyolo S, Mudhara M, & Wale E (2014). The impact of smallholder irrigation on household welfare: The case of Tugela ferry irrigation scheme in KwaZulu-Natal, South Africa. Water SA, 40 (1), 145–156.

Stevenson EGJ, Greene LE, Maes KC, Ambelu A, Tesfaye YA, Rhenigans R, & Hadley C (2012). Water insecurity in 3 dimensions: An anthropological perspective on water and women's psychosocial distress in Ethiopia. Social Science & Medicine, 75(2), 392–400. [PubMed: 22575697]

Subbaraman R, Nolan L, Sawant K, Shitole S, Shitole T, Nanarkar M, … Bloom DE (2015). Multidimensional measurement of household water poverty in a Mumbai slum: Looking beyond water quality. PLoS One, 10(7), e0133241. [PubMed: 26196295]

Sultana F, & Loftus A (2012). The right to water: Politics, governance and social struggles. New York, NY: Earthscan.

Swyngedouw E (2013). UN water report 2012: Depoliticizing water. Development and Change, 44(3), 823–835.

Tesfamariam BY, Owusu-Sekyere E, Emmanuel D, & Elizabeth TB (2018). The impact of the homestead food garden programme on food security in South Africa. Food Security, 10(1), 95–110.

Verzijl A, & Quispe SG (2013). The system nobody sees: Irrigated wetland management and alpaca herding in the Peruvian Andes. Mountain Research and Development, 33(3), 280–294.

Vörösmarty CJ, McIntyre PB, Gessner MO, Dudgeon D, Prusevich A, Green P, … Davies PM (2010). Global threats to human water security and river biodiversity. Nature, 467(7315), 555–561. [PubMed: 20882010]

Water Aid. (2016). Water: At what cost? The state of the world's water 2016. Briefing Report: WaterAid.

Weaver LJ, & Hadley C (2009). Moving beyond hunger and nutrition: A systematic review of the evidence linking food insecurity and mental health in developing countries. Ecology of Food and Nutrition, 48(4), 263–284. [PubMed: 21883069]

Whitney CW, Luedeling E, Hensel O, Tabuti JR, Krawinkel M, Gebauer J, & Kehlenbeck K (2018). The role of homegardens for food and nutrition security in Uganda. Human Ecology, 46(4), 497–514.

Workman CL, & Ureksoy H (2017). Water insecurity in a syndemic context: Understanding the psycho-emotional stress of water insecurity in Lesotho, Africa. Social Science & Medicine, 179, 52–60. [PubMed: 28254659]

World Health Organization. (2018). The state of food security and nutrition in the world 2018: Building climate resilience for food security and nutrition. Rome: Food & Agriculture Organisation.

Wutich A (2009). Intrahousehold disparities in women and men's experiences of water insecurity and emotional distress in urban Bolivia. Medical Anthropology Quarterly, 23(4), 436–454. [PubMed: 20092053]

Wutich A, & Brewis A (2014). Food, water, and scarcity toward a broader anthropology of resource insecurity. Current Anthropology, 55(4), 444–468.

Wutich A, Brewis A, Chavez JBR, & Jaiswal CL (2016). Water, worry, and Dona Paloma: Why water security is fundamental to global mental health. In Kohrt BA, & Mendenhall E (Eds.), Global mental health (pp. 57–72). New York: Routledge.

Wutich A, & Ragsdale K (2008). Water insecurity and emotional distress: Coping with supply, access, and seasonal variability of water in a Bolivian squatter settlement. Social Science & Medicine, 67(12), 2116–2125. [PubMed: 18954928]

Wutich A (2020). In this issue.

Young S, Collins S, SM GB, Neilands T, Jamaluddine Z, Miller J, … Wutich A (2018). Development and validation protocol for an instrument to measure household water insecurity across cultures and ecologies: The Household Water Insecurity Experiences (HWISE) scale. BMJ Open, 9(1), bmjopen–2018.

FIGURE 1.

Location of the 27 study sites across 21 low- and middle-income countries

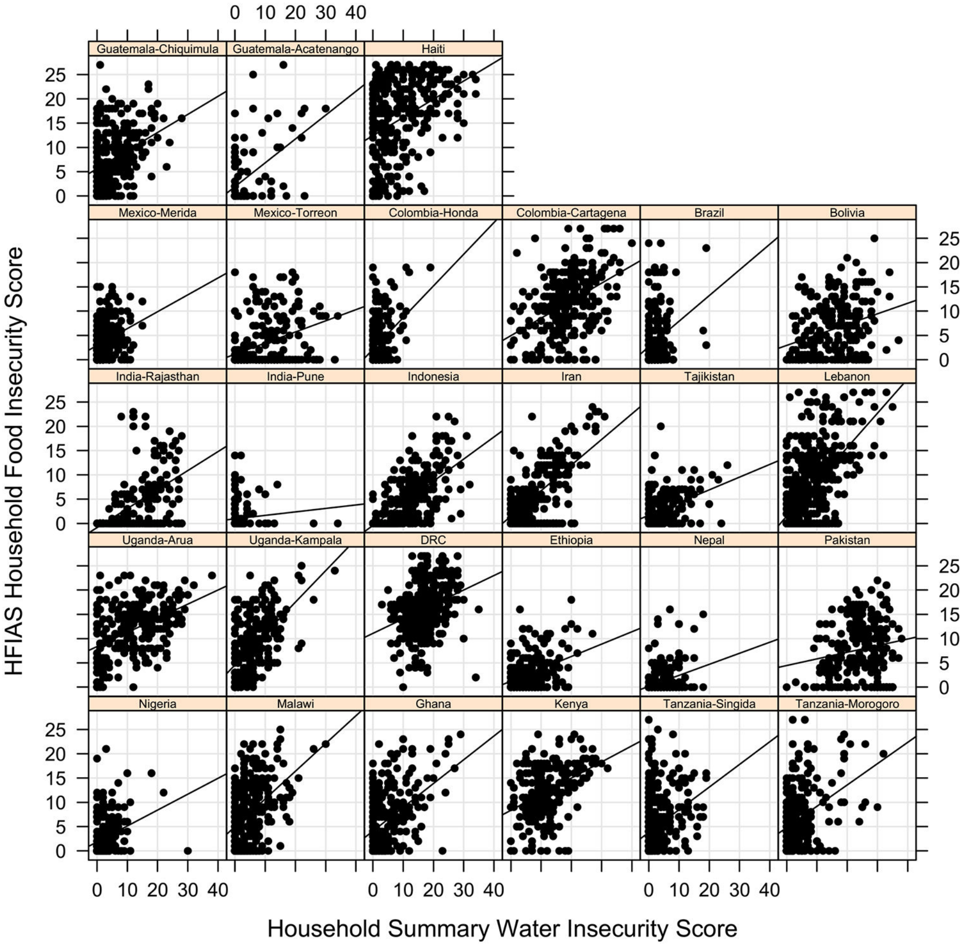

FIGURE 2.

Bivariate relationship between summary household food insecurity and summary water scores by site

TABLE 1

Study sites, sampling approach, and selected site characteristics

World region	Site	Sample size	Season	Sampling strategy	Primary source of drinking water (%)
Africa	Kahemba, DRC	392	Dry season	Cluster random	Surface water (99.7)
	Bahir Dar, Ethiopia	259	Rainy season	Stratified random	Unprotected dug well (25.1)
	Accra, Ghana	229	Rainy season	Stratified random	Bagged/sachet water (86.0)
	Kisumu, Kenya	247	Neither rainy nor dry	Simple random	Surface water (17.4)
	Lilongwe, Malawi	302	Neither rainy nor dry	Cluster random	Standpipe (45.4)
	Lagos, Nigeria	239	Rainy season	Multistage random	Bagged/sachet water (48.9)
	Morogoro, Tanzania	300	Rainy season	Cluster random	Standpipe (70.7)
	Singida, Tanzania	564	Dry season	Purposive	Standpipe (48.7)
	Arua, Uganda	250	Rainy season	Cluster random	Protected dug well (64.8)
	Kampala, Uganda	246	Dry season	Purposive	Stand pipe (68.3)
Europe and Central Asia	Dushanbe, Tajikistan	225	Dry season	Cluster random	Piped water (58.2)
Latin America and the Caribbean	San Borja	247	Dry season	Simple random	Standpipe (41.6)
	Ceará, Brazil	254	Neither rainy nor dry	Cluster random	Piped water (59.5)
	Cartagena, Colombia	266	Dry season	Simple random	Piped water (46.2)
	Honda, Colombia	196	Rainy season	Cluster random	Piped water (74.5)
	Acatenango, Guatemala	101	Dry season	Cluster random	Piped water (38.4)
	Chiquimula, Guatemala	314	Dry season	Systematic random	Bottled water (70.2)
	Gressier, Haiti	292	Dry season	Cluster random	Piped water (65.0)
	Mérida, Mexico	250	Dry season	Cluster random	Bottled water (50.0)
	Torreón, Mexico	249	Dry season	Stratified cluster random	Bottled water (70.2)
Middle East	Beirut, Lebanon	574	Rainy season	Cluster random	Small water vendor (54.5)
	Sistan and Baluchestan, Iran	306	Dry season	stratified random	Small water vendor (48.0)
South Asia	Labuan Bajo, Indonesia	279	Dry season	Simple random	Bottled water (36.9)
	Kathmandu, Nepal	263	Rainy season	Cluster random	Bottled water (49.8)
	Punjab, Pakistan	235	Dry season	Cluster random	Standpipe (26.6)
	Pune, India	180	Across multiple	Parallel assignment, nonrandom	Piped water (89.4)
	Rajasthan, India	248	Dry season	Stratified random	Tanker truck (55.2)

Note: For more detailed information on the study sites, see Young et al. (2018).

TABLE 2

HWISE candidate survey items used in this analysis to operationalize water insecurity by subdomain

Water insecurity subdomains	**In the last 4 weeks, how frequently…**[*]	**Subdomain extraction component (by PCA)**
Water quantity	Did you or anyone in your household worry you would not have enough water for all of your household needs?	0.440
	Has there not been enough water in the household to wash clothes?	0.542
	Have you or anyone in your household had to go without washing hands after dirty activities (eg, defecating or changing diapers, cleaning animal dung) because of problems with water?	0.578
	Have you or anyone in your household had to go without washing their body because of problems with water (eg, not enough water, dirty, unsafe)?	0.634
	Has there not been as much water to drink as you would like for you or anyone in your household?	0.636
	Have you or anyone in your household gone to sleep thirsty because there was no water to drink?	0.429
	Has there been no useable or drinkable water whatsoever in your household?	0.530
Water quality	Have you or anyone in your household drank water that looked, tasted, and/or smelled bad?	0.926
	Have you or anyone in your household drank water that you thought was unsafe?	0.926
Time and labor costs	Have problems with water prevented you or anyone in your household from earning money?	0.781
	Did the children in your household miss school or go to school late because of problems with water (eg, time spent fetching water, lack of water for bathing)?	0.749
	How long does it take to get water and come back? (minutes, categorized as 0, no time, 1 less than 1 hour/day, 2 more than 1 hour/day)[**]	0.664
Changing what was eaten	Have you or anyone in your household had to change what was being eaten because there were problems with water (eg, for washing foods, cooking)?	N/A

[*] Items were scores as 0 = never or not applicable, 1 = rarely (1–2 times), 2 = sometimes (3–10 times), 3 = often (11-20 times), or 4 = always (>20 times), with the exception of the question about duration (**), which was scored as 0 = no time, 1 = 1-59 minutes/day, 2≥1 hour/day). Items within each subdomain were summed, with the exception of changing what was eaten (only one item in that domain) and time spent collecting water, which was excluded because it was scored differently.

TABLE 3

Associations of summary score and subdomain of water insecurity with household food insecurity based on GLMM, with coefficient estimates, SE, *t* values, and approximated *P* values as significant at the 1% (***), 5% (**), and 10% (*) levels

	HFIAS score		
	Model 0	**Model 1**	**Model 2**
Summary household water insecurity score		0.330	
		(0.008)	
		t = 39.330***	
Water quantity subdomain score			1.809
			(0.103)
			t = 17.538***
Water quality subdomain score			0.460
			(0.088)
			t = 5.197***
Time/labor impacts subdomain score			1.146
			(0.120)
			t = 9.511***
Rural household (yes = 1)	0.550	0.091	−0.096
	(0.153)	(0.139)	(0.142)
	t = 3.596***	*t* = 0.658	*t* = −0.681
Perceived social status (1–10 scale)	1.177	0.764	0.766
	(0.030)	(0.029)	(0.029)
	t = 39.259***	*t* = 26.246***	*t* = 26.572***
Constant (study site)	−1.300	−1.091	1.511
	(0.210)	(0.191)	(0.202)
	t = −6.176***	*t* = −5.724***	*t* = 7.484***
N	7031	7031	7031
Log likelihood	−22 485.370	−21 785.920	−21 742.760

TABLE 4

Household water insecurity summary score association with household food insecurity subdomains, with coefficient estimates, SE, *t* values, and approximated *P* values as significant at the 1% (***), 5% (**), and 10% (*) levels

	Model 0	**Food quantity subdomain score Model 3**	**Food quality subdomain score Model 4**	**Food anxiety subdomain score Model 5**	**Frequency changing what was eaten Model 6**
Summary household water insecurity score		0.169	0.042	0.084	0.084
		(0.004)	(0.001)	(0.001)	(0.001)
		t = 37.856***	*t* = 30.378***	*t* = 84.690***	*t* = 84.690***
Rural household (yes = 1)	0.550	−0.392	0.074	−0.125	−0.125
	(0.153)	(0.074)	(0.023)	(0.016)	(0.016)
	t = 3.596***	*t* = −5.316***	*t* = 3.216***	*t* = −7.621***	*t* = −7.621***
Perceived social status (1–10 scale)	1.177	0.340	0.101	0.004	0.004
	(0.030)	(0.015)	(0.005)	(0.003)	(0.003)
	t = 39.259***	*t* = 22.044***	*t* = 20.926***	*t* = 1.171	*t* = 1.171
Constant (study site)	−1.300	−0.785	−0.131	−0.060	−0.060
	(0.210)	(0.101)	(0.032)	(0.022)	(0.022)
	t = −6.176***	*t* = −7.764***	*t* = −4.141***	*t* = −2.664***	*t* = −2.664***
N	7031	7031	7031	7031	7031
Log likelihood	−22 485.370	−17 323.860	−9148.264	−6760.136	−6760.136