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Research Article

Keywords: Water insecurity, Ethiopia, Parallel analysis, Factor analysis

Posted Date: August 12th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-10360857/v1>

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Additional Declarations: No competing interests reported.

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Abstract

Background: Water insecurity is a common challenge in resource-constrained settings that particularly impacts women. Locally adapted and validated water insecurity measures provide a more robust basis for intervention. Our aim was to culturally adapt and psychometrically validate the HWISE scale for Sidaamu Afoo speakers using ordinal response categories rather than truly continuous measurements.

Methods: We explored factors using Horn's Parallel Analysis on a polychoric correlation matrix, which accounts for ordinal response categories. Data suitability was confirmed by Kaiser-Meyer-Olkin and Bartlett's sphericity indices. We validated psychometric properties using data from 264 randomly selected adult Sidaamu Afoo-speaking women in Ethiopia. Reliability was assessed via classical test theory, using the ordinal coefficient α for internal consistency and the intraclass correlation coefficient (ICC) for temporal stability. Statistical analyses were performed using R.

Results: The Kaiser-Meyer-Olkin value of 0.942 confirmed the sampling adequacy of each item and the HWISE scale. A significant Bartlett's test ($p < 0.05$) indicated that the correlation matrix was suitable for factorization. The adapted HWISE scale presented a unidimensional structure, driving 67.6% of total variance. The items demonstrated internal consistency ($\alpha = 0.96$) and

stability across repeated measures ($ICC = 0.93$). The scale further showed convergent validity, confirmed by a significant correlation with external constructs, and discriminant validity, distinguished by known-group differentiation.

Conclusion: The adapted HWISE scale proved valid and reliable in measuring retrospective water insecurity experiences among Sidaamu Afoo-speaking adult women in Ethiopia. Future studies should diversify their sample and address seasonal variations.

Keywords: Water insecurity, Ethiopia, Parallel analysis, Factor analysis

1. Introduction

Human health is predicated on access to safe, reliable, sufficient, and affordable water [1,2]. Current trends, however, indicate that global water insecurity is escalating, given extreme weather events (e.g., drought) and resource demands (e.g., overconsumption). Globally, approximately 2-3 billion people are affected by this multidimensional problem [3]. By 2030, such conditions are expected to affect 50% of the global population [4], and the achievement of the water-related Sustainable Development Goal [4,5].

Resource-poor settings [6], such as Ethiopia, face massive water supply infrastructure gaps and variable lower coverages, increasingly placing Ethiopians at risk. Recent national evidences noted that approximately half (50%) of households in Ethiopia lacked basic water services. The remained 15%, 24% and 11% were, respectively, accessing unimproved, limited and surface water sources [7]. Limited provisions exacerbate water insecurity experiences across vulnerable communities, particularly for women with children under five [8]. Moreover, the increased water supply infrastructure distribution inequalities along with frequent interruptions in supply are associated with worse health outcomes [8,9]

Thus, measuring household water insecurity experiences in Ethiopia using robust, locally adapted metrics is vital to understanding the possible risks to and exposure statuses of vulnerable populations, in addition to interventions that have positive impacts on health and wellbeing. Regarding existing inequalities in access, scales relevant to minoritized populations and women are especially important. The HWISE scale has become a standard measure of water insecurity [10]. Local adaptations have been developed in Kenya [11], Ethiopia [12–14], Nepal [15], Bolivia and Tanzania [16], Cameroon [17], and Lesotho [18]. Across these regions, however, the local HWISE scales demonstrated different analytic approaches with varying underlying constructs. Several studies [12,16,17] reported a unidimensional factor structure with good psychometric properties; meanwhile, others studies [13,15] demonstrated a multidimensional HWISE scale, noting the context specific scale presentation.

For instance, a previous adaptation from Ethiopia [12] reported scale dimensionality through an exploratory factor analysis (EFA) and the use of Cronbach's alpha. The items' Likert response

options were not robustly dealt with, potentially leading to biased parameter estimations [19,20]. Altogether, we are focused on developing a scale that recognizes women as those responsible for acquiring water. Women, therefore, carry more of water insecurity's burden in Ethiopian households [17,21]. Thus, this study aimed to culturally adapt and psychometrically validate the Household Water Insecurity Experiences (HWISE) scale for use in the Ethiopian context. Recognizing women as primary informants on household water insecurity, the study specifically evaluated the reliability and validity of the adapted scale among Sidaamu Afoo-speaking women in southern Ethiopia.

2. Methodology

2.1. Study area

A community-based cross-sectional study was conducted to evaluate construct validity and the reliability (internal consistency and test-retest) of the locally adapted HWISE scale. This study was conducted in the Sidama National Regional State (SNRS), 275 kilometer south of Addis Ababa, the capital. The SNRS is situated northeast of Lake Abaya and southeast of Lake Hawassa and geo-positioned between 6°14'54" and 7°15'10" north latitude and 37°10'05" and 39°15'01" east longitude. According to recent estimates, the regional total population is reaching 4.7 million, with the average population density of 674 persons per square kilometer, one of the most densely populated regions across Ethiopia [22,23]. The region is administratively divided into 4 zones, which are further subdivided into 31 districts and 1 city administration. In the Hawassa Zuria district (HZD), one of several drought-prone districts in the region, where water scarcity is often a challenge. Small-holder farmers in this district face severe water shortages, which escalates increased exposure to household water insecurity [23,24].

2.2. Data collection stages

Two interdependent data collection stages (Figure 1) were used to collect the data, which took place from 1 to 28 February 2024.

2.2.1. Stage I: Cultural Adaptation

Cultural adaptation of the HWISE scale was based on the recommended multi-step systemic procedures [25]. This approach ensures that there is conceptual equivalence between the targeted and the original version scales. As such, a set of interrelated steps (e.g., forward translation, back translation, content validity analysis, followed by cognitive interviews) were completed sequentially.

2.2.1.1. Translation

Data collection tools were translated from English into Sidaamu Afoo by three experts who were native Sidaamu Afoo speakers and fluent in English. The translated version was then back-translated into English by two independent translators who had not been involved in the initial

English-to-Sidaamu Afoo translation. Conceptual equivalence between versions was maintained while preserving the original meaning, cultural context, and related considerations [28]. Translators identified ambiguous phrases and/or words lacking equivalent local terms. For example, there was no targeted equivalent for the original phrase, “*in your household*.” The suggested alternatives (i.e., “in your family” and “in your home”) were presented. A consensus was then reached to use the more culturally appropriate phrase, “*in your home*”, as it holds broader use and meaning across the context. Through this, the Sidaamu Afoo version was synthesized.

2.2.1.2.Content Validity Analysis

The pre-final version underwent content validation, aimed to assess the resemblances between versions [26,27] and generate content validity index (CVI). Lawshe [28] recommended selecting a panel of up to 10 experts for content validity assessment or rating. As such, the 10 experts included: 2 Environmental Health; an Epidemiologist; a Biostatistician; 2 Water Supply, Sanitation, and Hygiene; 2 Sidaamu Afoo folklore; and 2 English Language and Communication experts were presented to rate the relevance of 12 items. The rating was based on a 4-point Likert-scale, where: 1 = ‘not relevant’; 2 = ‘somewhat relevant’; 3 = ‘quite relevant’; and 4 = ‘highly relevant’ for the original scale [26].

2.2.1.3.Cognitive Interviews

Relevant items underwent cognitive interviews to assess and adjust for linguistic accuracy, cultural adaptability, and refine items to suit the context. This was done using the qualitative approach through which respondents’ understanding, interpretation, and/or mental processing or rephrasing of the given items were evaluated [29]. This also minimizes the measurement error [30,31] while maximizing the item’s clarity and comprehension.

A purposely selected 15 adult women were used for cognitive interview. To increase response heterogeneity, different socioeconomic statuses (e.g., age, occupation, and education) were considered (Table 1). The adapted HWISE scale was then presented with a semi-structured interviewer guide, where suggestions were collected [30,31]. Moreover, the ‘think-aloud’ with verbalized reflection technique was also employed [29]. Items were well understood, but for the

12th item (Box 1), where the phrase '*feeling insecure*' was not rephrased among three respondents. The probe presented under this item was thus became the focus of the final interview.

Table 1. Sociodemographic characteristics of women took part in cognitive interviews

Variables	Category	Frequency (%)
Age	Mean ($\pm$ SD)	28.5 (7.2)
Occupation	Farming	7 (46.7)
	Own business	3 (20.0)
	Salary	5 (33.3)
Education	No formal education	5 (33.3)
	Formal education (grades attended)	6 (40.0)
	Higher education attended	4 (26.7)

We also used the cognitive interview to evaluate the length of interviewing; enumerators' familiarity with the scale, minimizing interviewer bias; and, uniform administration of the candidate scale, to focus on the upholding an unbiased demeanor.

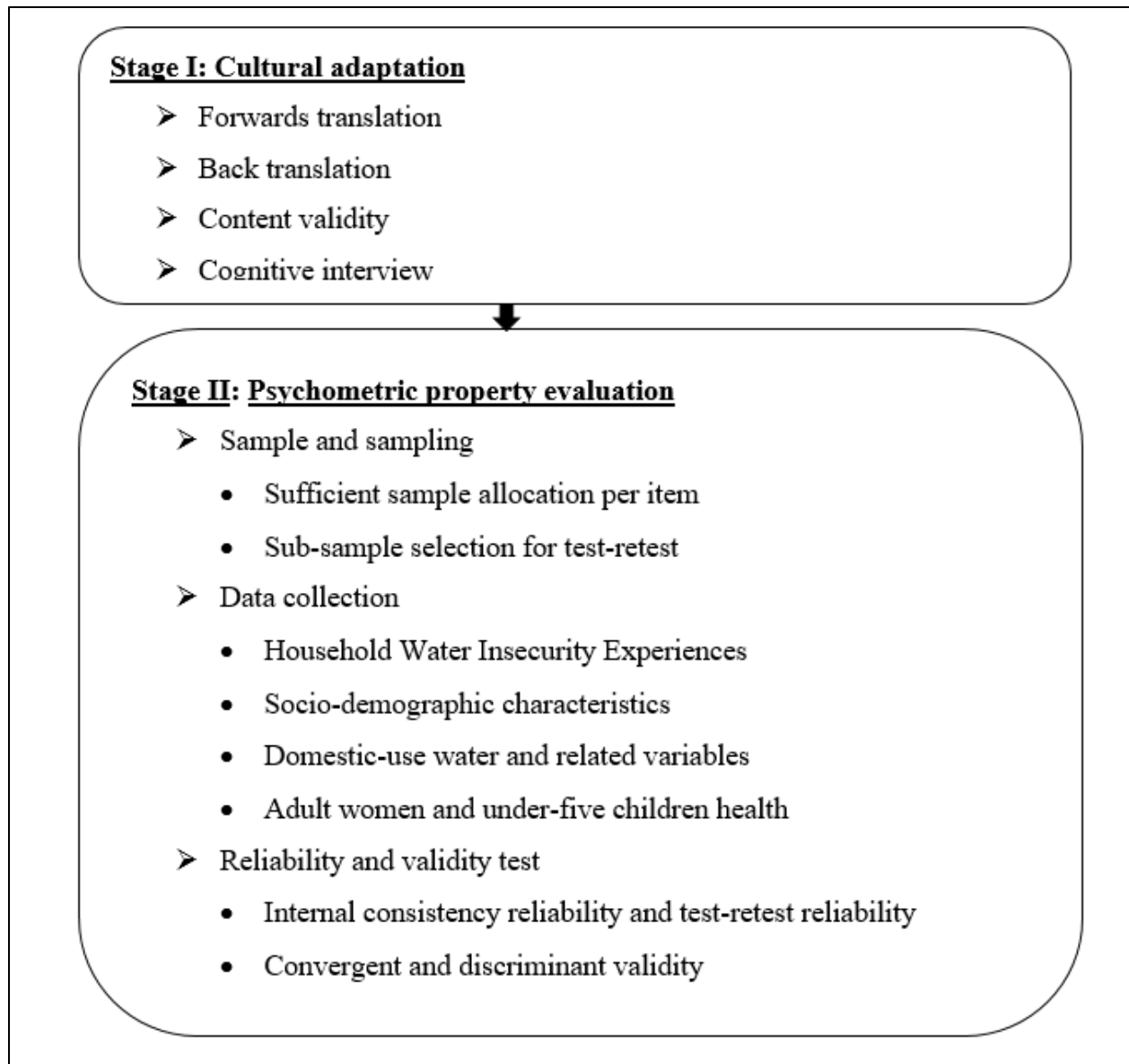


Figure 1 Schematic procedures to adapt and evaluate psychometric properties of the HWISE scale for Sidaamu Afoo speakers in Ethiopia

2.3. Stage II: Psychometric property evaluation

2.3.1. Sample Population

Scale adaptation and psychometric validation were grounded in the principles of Consensus-based Standards for the Selection of Health Measurement Instruments (COSMIN) [32]. Sampling adequacy was determined while allocating sufficient sample per item, which increases the

likelihood of retaining the dominant factor [33]. The sample-to-item ratio with varying likelihood of retaining the dominant factor: a 5:1 ratio gives a 40%; whereas, a 10:1 ratio increases the likelihood to 60% [34] was previously suggested sample allocation methods. Recent studies [33] recommended the use of 20:1 sample-to-item ratio, which demonstrates a 70% likelihood of identifying dominant factor. Altogether, a maximum of 264 study participants, with a 10% non-response rate, were considered. About 40% of this sample [35] consisted of 106 adult women with children under-five who were revisited to assess the test-retest reliability across measurements. These women were part of the baseline study and re-interviewed to determine the scale's stability.

2.3.2. Ethical Approval

The study protocol was approved by the Institutional Review Board of Hawassa University College of Medicine and Health Sciences (Reference Number: IRB07516) in accordance with the principles of the 1996 Helsinki Declaration and the specific guidelines and regulations set by the University. The study participants were presented with a consent to participate form, and their consent, with a signed mark, was obtained before beginning the study. They were also assured that they could voluntarily participate, with the awareness to discontinue their responses at any point when they feel, or otherwise to finish.

2.3.3. Sampling Procedures

The HZD, one of the 4 districts in the Northern Sidama zone, and frequently hit with drought, was purposely selected for this study. Furthermore, two rural kebeles (the lowest administration level in Ethiopia [36]), Jara Daamuwaa (among the low land kebeles) and Shaamena Germama (among highland kebeles) to accommodate variations in altitudes were randomly selected. This variation was taken into account to represent the distribution of water supply infrastructure and how water kiosk reliability is affected by local terrain, landscape, and geography [37]. This was also supported by the research team's situational analysis, reporting drinking water infrastructure distribution varies with rising altitude. Water pressure or flowrate inconsistency varied across elevations, escalating intermittency [37] and exacerbates the household water insecurity [38].

Community-level health information registers, serving as a household profiling data-base for primary health service units [39], were used to prepare a list of eligible women with under-five children. Participants were then selected using randomized computer-generated numbers.

Respondents included women 18 years and older, fluent Sidaamu Afoo, women with a child under five, and women resided in the study villages for at least 6 months were included for this study. Whereas, women not willing and/or unable to participate due to some conditions (e.g., chronic illnesses), those with conditions hindering water collection (e.g., physical disability), and not fluent Sidaamu Afoo were not recruited.

2.3.4. The Household Water Insecurity Experiences Scale

The HWISE scale is the standard metric presented in English [10]. While developing the scale, adults aged 16 or 18 years (recognized for their better knowledge of domestic water collection, management, and use) were recruited from 8,127 households across low- and middle-income countries (LMICs). The HWISE scale (Box 1) is composed of 12 measurement items, retrospectively measuring the four water insecurity dimension of adequacy, accessibility, reliability, and safety. Experiences with water encompass drinking, washing, bathing, cooking, and psychosocial experiences associated with utilization [10]. Overall, the scale addresses hygienic aspects of water use (handwashing) and psychosocial distress (worry and anger) linked to water insecurity [40].

The HWISE scale exhibited acceptable internal consistency with Cronbach's $\alpha > 0.80$ and was valid across diverse settings, proving effective for assessing water insecurity in LMICs. The response options are frequency based and presented as ordinal or categorical 4-point Likert-type of 0, 1, 2, and 3 (i.e., 0 for "never experiencing", 1 for "rarely experiencing", "2" for "sometimes experiencing", 3 for "often or always experiencing"). Additionally, a response frequency (0-39) was used to measure the level of water insecurity or prevalence for each item. Higher scores indicated severe household water insecurity. Moreover, a provisional cut-point greater than or equal to 12 was set to indicate water insecurity prevalence. Items responded to with "Do not know" or "no answer" were invalidated or rejected from the analysis [10].

Box 1 List of the 12 items measuring HWISE scale

Label	Items Description
Worry	In the last 4 weeks, how frequently did you or anyone in your household worry you would not have enough water for all of your household needs?
Hands	In the last 4 weeks, how frequently have you or anyone in your household had to go without washing hands after dirty activities (e.g., defecating or changing diapers, cleaning animal dung) because of problems with water?
Plans	In the last 4 weeks, how frequently has you or anyone in your household had to change schedules/plans due to problems with your water situation, such as problems getting or distributing water within the household? (Activities that may have been interrupted include caring for others and doing household chores)
Drink	In the last 4 weeks, how frequently has there not been as much water to drink as you would like for you or anyone in your household?
Interrupt	In the last 4 weeks, how frequently has your household water supply from your main water source been interrupted or limited (e.g., water pressure, less water than expected)?
Clothes	In the last 4 weeks, how frequently has there not been enough water in the household to wash clothes?
Food	In the last 4 weeks, how frequently have you or anyone in your household had to change what was being eaten because there were problems with water (e.g., for washing foods and cooking)?
Bathe	In the last 4 weeks, how frequently have you or anyone in your household had to go without washing their body because of problems with water (e.g., not enough water, dirty, and unsafe)?
Angry	In the last 4 weeks, how frequently did you or anyone in your household feel angry about your water situation?
Sleep	In the last 4 weeks, how frequently have you or anyone in your household gone to sleep thirsty because there was not any water to drink?
None	In the last 4 weeks, how frequently has there been no useable or drinkable water whatsoever in your household?
Shame	In the last 4 weeks, how frequently have problems with water caused you or anyone in your household to feel ashamed/excluded/stigmatized?

Note: Responses options: never implies 0 times, rarely is for 1–2 times, sometimes is for 3–10 times, and often and/or always represents water insecurity experiences for greater or equals to 11 times.

2.3.5. Data collection procedures

A one-to-one interviewer-administered method was employed to collect data on: socio-demographic characteristics; retrospective water insecurity experiences; **domestic-use** water supply, water collection and related characteristics; and women and under-five child health situations. Socio-demographic characteristics included participants' age, marital status, family size, religion, occupation, and education using the data collection questionnaire adopted from the literatures [36,41]. The adapted HWISE scale was used to record water insecurity experiences for previous 4-weeks. Domestic-use water supply was assessed using the adapted questionnaire of joint monitoring programme for water supply, sanitation and hygiene [42]. The 2018 updated core questions includes access to and type of water source, time spent collecting water (minutes), cost of purchasing water (ETB) and the amount of water used (liters). Additionally, data on previous 12-month history of women's injury related to water fetching (e.g., falls, futures, slipping) [10,11] and the history of two-week diarrhea morbidity among children <5 [42,43] were collected.

Kobo Toolbox (kf.kobotoolbox.org/#/projects/home), a user-friendly smartphone application, was employed during data collection. Voice recordings and the geographical positioning system were recorded and used for additional tracking. Enumerators, unaffiliated with local water, sanitation, and hygiene intervention programs, holding a bachelor's degree in environmental health were recruited. Fluency in Sidaamu Afoo and understanding of the local context were considered to recruit the enumerators. Moreover, enumerators underwent three-days of training, aimed at ensuring consistent instrument administration and capturing of responses. Daily review sessions were used for quality assurance.

Data quality was maintained through using culturally adapted and validated scale. The the items measuring the HWISE scale were presented with possible probes supporting respondents to recall the frequency on the retrospective water insecurity experiences [10]. Interviewer bias reduction was addressed by maintaining a neutral demeanor to prevent inaccurate responses and enhance the

response quality. Social desirability bias reduction [44] was also achieved through a consistent one-to-one interviews in distraction-free spaces. Enumerators were trained and pretested the data collection tool before the actual study commencement. Thus, variation among enumerators was minimized and comparability with other studies was maximized by training based on the standard HWISE standard interviewer guide.

2.3.6. Statistical Analysis

Data was cleaned to maintain completeness and consistency, then analyzed using R (statistical computing version 4.5.2) with lavaan packages properly loaded. Descriptive statistics were used to report the participants' profile and their aggregate HWISE score; meanwhile, inferential statistics were used to report psychometric properties of the scale. The principle of Classical Test Theory (CTT) was used to analyze the scale's validity and reliability. CTT models an individuals' observed score into a true value and random error attributed to the measurement [45].

2.3.6.1. Content validity analysis

Item relevance was rated using a 4-point Likert-scale: 1 = 'not relevant'; 2 = 'somewhat relevant'; 3 = 'quite relevant'; and 4 = 'highly relevant' [26,27]. Values 1 or 2 were categorized as 'not relevant' and coded as 0, while either 3 or 4 to witness the item's relevance to the measured domain and coded as 1. The summed value of relevance was divided by the number of experts to generate the indices: item-level content validity index (I-CVI) and scale-level content validity index (S-CVI) [26,27]. To compute I-CVI, the sum of the agreements value for each item was divided by the total number of experts [28]. To calculate S-CVI, the score for each 12-items were added and then divided by the total number of experts. The minimum acceptable CVI threshold values exceed 0.75 and 0.8 for I-CVI and S-CVI, respectively [26,27].

2.3.6.2. Construct Validity Analysis

Construct validity was assessed through an exploratory factor analysis (EFA). The Kaiser-Meyer-Olkin (KMO) index was used to assess sampling adequacy and determines the proportion of shared variance [46]. KMO values ranges between 0 and 1, with $KMO > 0.90$ representing excellent sampling adequacy [33]. Bartlett's test of sphericity examines the hypothesis of homogeneity of

correlation and identifies the degree of interrelationships while comparing the correlation matrix to an identity matrix. A significant chi-square result ($P < 0.05$) in the sphericity test confirmed a strong correlation [33], rejecting the null hypothesis. Communality (h^2) was assessed to evaluate the proportion of shared or common variance among measured items. When h^2 is higher than 0.4, it implies that substantial variance is shared among the items, and thus, data factorability [47].

The EFA performance was guided with the Weighted Least Squares Mean and Variance-adjusted (WLSMV) estimation for ordinal data was used. Horn's PA was used along with the Kaiser criterion (with eigenvalue ≥ 1) [48] and a Cattell Scree Plot [49], to determine the underlying construct. Horn's PA is well suited for an ordinal Likert-rating scale with non-normal distribution [50]. Cattell theorized that insignificant factor(s) would follow genuine factor(s) and can be identified by an "elbow" or clear slope break in the scree plot. The use of these classical methods often estimate the biased number of factors or overestimate when applied to ordinal Likert-type responses with possible skewness. Horn's PA compares the observed (real) eigenvalues with simulated data-based eigenvalues, a randomly generated similar data by the Monte Carlo Simulation technique (500 simulations) [51]. Underlying factor (construct) with a real-data-based eigenvalue greater than the simulated eigenvalue was retained. This was supported by an oblique (promax type) rotation due to the observed high correlation among measured variables.

2.3.6.3. Reliability Analysis

Reliability is defined as the proportion of true score variance, suggesting that the measured score is affected by a minimal measurement error. Instead of Cronbach's alpha (α), an estimate based on the Pearson correlation matrix targeted to normality assumptions with tau-equivalence. This estimate can lead to coefficient underestimation when used with ordinal data; ordinal coefficients of α , a reliability estimate for PCM [20], was estimated here. At 95% CI, an α value of 0.8 and higher indicates good internal consistency, with the lower bound verifying contamination status [52], and deciding the level of internal consistency. Guttman Lambda 6 (G6), an alternative estimate, resulted [53] in higher values, supporting excellent internal consistency reliability. The α value was further interpreted using Feldt and Duhachek's reliability [54].

Test-retest reliability was examined using the intra-class correlation coefficient (ICC) [55,56]. Adhering to methodological guidelines [55–57], a two-week interval was used to obtain responses stability estimate using similar items from the same enrollees. They were unlikely to remember former responses, while this timeframe remains short enough to generate new insights. ICC further mitigates threats to validity, such as recall bias and actual changes in measuring constructs [58]. The responses' independence is essential to avoiding unbiased estimates of the scale's temporal stability [59]. The resulting ICC value > 0.70 indicates acceptable stability [55,56]. The ICC estimate was based on a two-way random mixed-effects model for an absolute agreement [60], declaring consistency of the measurement.

2.3.6.4. Convergent and Discriminant Validity

Convergent and discriminant validity of the adapted HWISE scale were analyzed while comparing scores to theoretically proven external constructs to evaluate the relationship between the theoretically related and unrelated constructs. This was grounded on psychometric analysis literature [10,11,17]. Convergent validity was assessed using a non-parametric alternative, Spearman's correlation (ρ). The correlation between the scores of adapted HWISE and the volume of water consumed per 24 hours, time (in minutes) spent collecting water, and cost of provisions. An indirect association between HWISE scores and the volume of water consumed per 24-hour period was expected, whereas a direct association was expected between the time spent fetching water and cost [10,11,17].

Discriminant or divergent validity was assessed when comparing the sum of ranks between independent samples belonging to known groups using the Mann-Whitney U test. This test accounts for non-normally distributed data. The sum of ranks was compared for (a) adult women who experienced injuries while collecting domestic-use water vs. without, (b) households with access to unimproved versus improved water sources, and (c) households with children under-five with a two-week history of diarrhea versus without. Overall, the Mann-Whitney U statistic was used to position the differences between comparative groups.

3. Results

3.1. Sociodemographic characteristics

The mean ($\pm$ SD) age of the adult women was 29.6 (6.3) (Table 2). More than nine in ten women ($n = 243$, 92.0%) were married. Moreover, a majority of the women ($n = 195$, 73.9%) had received formal education. Farming was the leading ($n = 258$, 97.7%) occupation. Approximately 57.2 % of respondents ($n = 151$) were dependent on a single income source, while 42.8% ($n = 113$) maintained an income anchored to multiple sources.

Table 2 Descriptive statistics of respondents

Variables (n=264)		Category	Frequency (%)
Age		Mean ($\pm$ SD)	29.8 (6.4)
Religion		Protestant	229 (86.7)
		Muslim	17 (6.4)
		Orthodox	9 (3.4)
		Catholic	9 (3.4)
Marital status		Married	245 (92.8)
		Other status	19 (7.2)
Education		No formal education	49 (18.6)
		Formal education (grades) attended	195 (73.9)
		Higher level of education attended	20 (7.6)
Occupation	Farming	No	6 (2.3)
		Yes	258 (97.7)
	Merchant	No	164 (62.1)
		Yes	100 (37.9)
	Employed	No	240 (90.9)
		Yes	24 (9.1)
	Others		7 (2.6)
Income sources		Single income source	151 (57.2)
		Multiple income sources	113 (42.8)

Aggregated HWISE scores followed a non-normal pattern of distribution, confirmed by skewedness, Kurtosis, and a significant ($p < 0.001$) Shapiro-Wilk test [61]. The mean value for items ranged from 2.39 to 2.84 (Table 3). The majority ($n = 209$, 79.2%) of adult women reported having experienced water insecurity in the previous 4 weeks.

Table 3 Descriptive statistics for the adapted HWISE scale in Ethiopia

Items	Mean ($\pm$ SD)	Skewness	Kurtosis
Worry	2.83 (0.95)	-0.48	-0.67
Interrupt	2.81 (0.89)	-0.40	-0.55
Clothes	2.65 (1.10)	-0.27	-1.25
Plans	2.70 (1.03)	-0.27	-1.07
Food	2.50 (0.97)	0.00	-0.99
Hands	2.39 (1.03)	0.01	-1.18
Body	2.42 (1.04)	0.12	-1.16
Drink	2.65 (1.04)	-0.27	-1.10
Angry	2.84 (1.02)	-0.50	-0.88
Sleep	2.45 (1.03)	0.03	-1.16
None	2.84 (0.91)	-0.46	-0.57
Shame	2.60 (1.00)	-0.11	-1.06

3.2.Content Validity and Cognitive Interview Analysis

Regarding the content validity index (CVI), each item was relevant to their respective measured HWISE domain; thus, none of the items were subjected to rejection or modification (Table 4). The adapted HWISE scale demonstrated excellent content validity [26,27], with the I-CVI exceeding the acceptable threshold value of 0.7 ($I-CVI \geq 0.8$) and an S-CVI score of 0.9.

Table 4 Content validity indices for the adapted HWISE scale in Ethiopia

Items	Experts' evaluation on item relevance										I-CVI
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Expert 9	Expert 10	
Worry	1	1	1	1	1	1	1	1	1	1	1.0
Hands	1	1	1	1	0	1	1	1	1	1	0.9
Plans	1	0	1	1	1	1	1	1	1	1	0.9
Drink	1	1	1	1	1	1	1	1	1	1	1.0
Interrupt	1	1	1	1	1	1	1	1	1	1	0.9
Clothes	1	0	1	1	1	1	1	1	1	1	0.9
Food	1	1	1	1	1	1	1	1	1	1	1.0
Bathe	1	1	1	1	1	1	1	1	1	1	0.9
Angry	0	1	1	1	1	1	1	1	1	1	0.9
Sleep	1	1	1	1	1	1	1	1	1	1	1.0
None	1	1	1	1	1	1	1	1	1	1	1.0
Shame	1	1	1	1	1	1	1	1	1	1	0.9
Mean score	0.9	0.8	1	0.9	0.8	0.9	1	1	1	1	0.9

Eleven items were reported as comprehensible by a majority of respondents (n =12, 80%); meanwhile, item number 12 (In the last 4 weeks, how frequently have problems with water caused you or anyone in your household to feel ashamed/excluded/stigmatized?) required clarification for three participants. The term '*shame*' delivered multiple meanings; however, it was replaced with contextually appropriate alternative (In the last 4 weeks, how frequently have problems with water caused you or anyone in your household to *feeling insecure*?) to better describe water experiences.

3.3.Construct Validity Analysis

KMO value of 0.924 indicated marvelous measures of sampling adequacy (MSA) with sufficient common variance. The MSA surpassed the minimum threshold of 0.5 for each item. Moreover, a significant ($P < 0.05$) Bartlett's test implied amenable data for factorization. The null hypothesis of the unit matrix structure was rejected following differences in the obtained correlation [33].

According to Horn's PA, the adapted HWISE scale demonstrated a unidimensional latent variable, explaining 67.6% of the variance. Results for the comparative eigenvalues are presented in Table 5. The first factor (eigenvalue = 8.420) dominated the observed data with larger real data-driven eigenvalues, compared to the counterparts generated from simulated data-driven eigenvalues of similar dimension. The rest of the factors showed consistently lower real data-driven eigenvalues, failing to represent the measured domain. The unidimensional structure was further confirmed with the graphical scree plot visualization, where a single factor presented an eigenvalue above 1.00 (Figure 1). Thus, the HWISE scale measures unidimensional factor, the household water insecurity.

Table 5 Horn's Parallel Analysis for the adapted HWISE in Ethiopia

Factors	Mean eigenvalues for the real data	Mean eigenvalues for the simulated data	Decision to factor retention
1*	8.420	1.366	Retained
2	0.842	1.260	Non-retained
3	0.724	1.187	Non-retained
4	0.398	1.123	Non-retained
5	0.307	1.065	Non-retained

6	0.273	1.019	Non-retained
7	0.245	0.962	Non-retained
8	0.209	0.911	Non-retained
9	0.200	0.857	Non-retained
10	0.173	0.807	Non-retained
11	0.124	0.754	Non-retained
12	0.088	0.688	Non-retained

* The retained dominant factor for the adapted HWISE scale

Moreover, the unidimensional structure was confirmed with strong factor loadings from EFA. The item 'Angry' was loaded with 0.887, the highest factor loading followed by 'Shame' with 0.877. The lowest factor loading value of 0.674 was observed for the item 'Interrupt'; however it still contributed significantly to the unidimensional structure (Table 6).

Scree plot

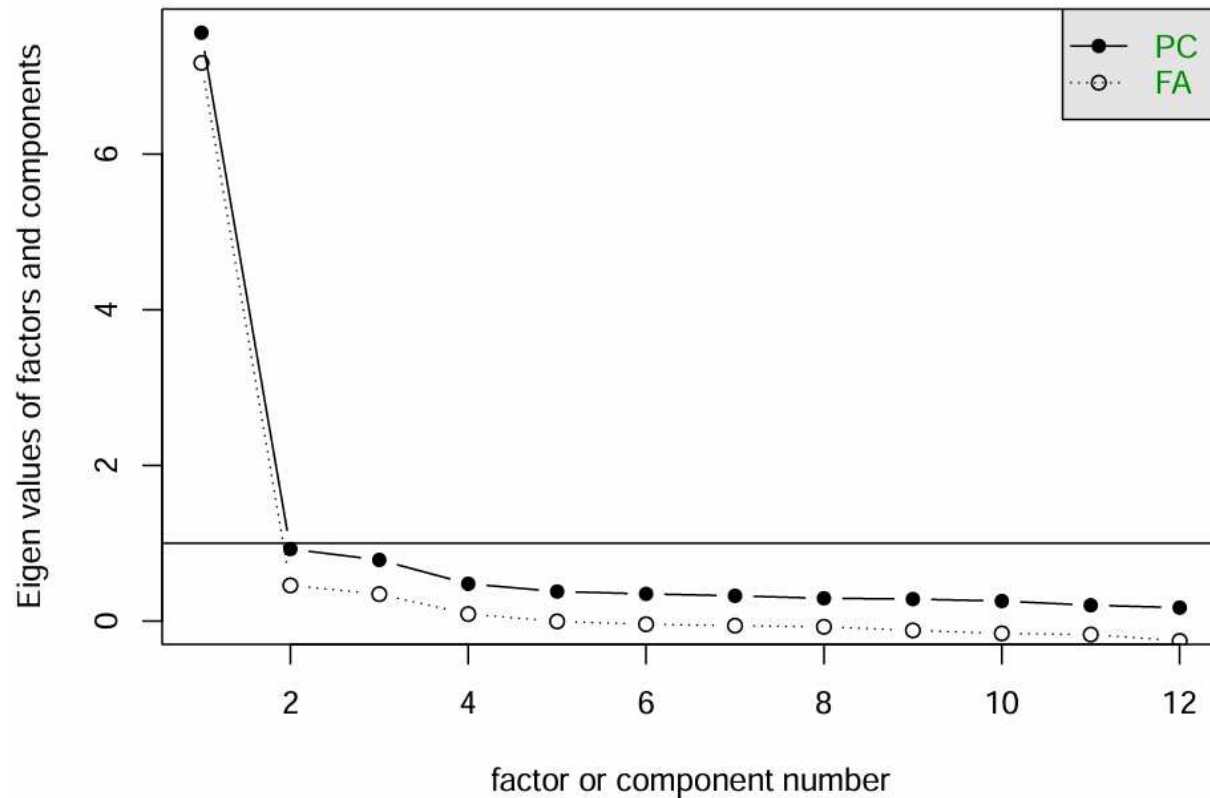


Figure 2 Parallel analysis with scree plots presentation for the adapted HWISE in Ethiopia

In the Polychoric correlation matrix (Table 7), the bivariate ρ ranged between 0.479 and 0.818. As observed, the lower value for ρ surpassed the minimum correlation coefficient of 0.30, thus indicating a strong and sufficient correlation.

Table 6 Construct validity analysis for the adapted HWISE

Items	EFA			
	Communality (h^2)	MSA with KMO	Standardized loadings	Uniqueness
Worry	0.574	0.956	0.757	0.430
Interrupt	0.454	0.854	0.674	0.546
Clothes	0.706	0.900	0.840	0.295
Plans	0.673	0.932	0.821	0.326
Food	0.712	0.953	0.844	0.286
Hands	0.713	0.936	0.845	0.284
Body	0.752	0.903	0.867	0.248
Drink	0.745	0.945	0.863	0.253
Angry	0.788	0.946	0.888	0.214
Sleep	0.691	0.964	0.831	0.307
None	0.532	0.880	0.730	0.467
Shame	0.769	0.946	0.877	0.230

MSA = Measures of sampling adequacy

3.4. Reliability Analysis

An ordinal alpha (α) value of 0.96 (95% CI [0.92, 0.99]) and G6 estimate between 0.96 and 0.97, demonstrated excellent reliability in internal consistency (Table 8). It was supported by average inter-item correlations between 0.66 and 0.69, an indication of minimal variability that further confirms unidimensional structure. Moreover, item-rest correlations showed strong relationships between individual items and the total score, with corrected item–total correlations values between 0.70 and 0.89. This further confirmed substantial contribution of each item to the scale’s strong reliability.

iability. If the item dropped, the α value remain in between 0.67 and 0.87, confirming the scale's internal consistency do not improve after deletion of any single item. All of the items consistently contributed to the scale, surpassing the minimum threshold value (≥ 0.3) and further supporting strong discrimination.

Table 7 Polychoric correlation matrix for the adapted HWISE

Items	Worry	Interrupt	Clothes	Plans	Food	Hands	Body	Drink	Angry	Sleep	None
Interrupt	0.708										
Clothes	0.623	0.619									
Plans	0.626	0.603	0.786								
Food	0.597	0.540	0.735	0.771							
Hands	0.585	0.479	0.761	0.755	0.766						
Body	0.619	0.514	0.798	0.731	0.743	0.814					
Drink	0.609	0.507	0.668	0.681	0.699	0.767	0.722				
Angry	0.681	0.625	0.672	0.697	0.713	0.698	0.746	0.818			
Sleep	0.613	0.511	0.652	0.646	0.728	0.694	0.667	0.781	0.781		
None	0.626	0.606	0.525	0.482	0.545	0.503	0.659	0.643	0.716	0.626	
Shame	0.638	0.504	0.720	0.620	0.737	0.733	0.750	0.824	0.810	0.774	0.733

The adapted HWISE scale demonstrated strong test-retest reliability (ICC = 0.93 (95% CI [0.90, 0.95], $p < 0.01$), promising temporal stability and consistency of the measurement items across observations [55,56].

Table 8 Reliability statistics for the adapted HWISE scale in Ethiopia

Items	Average inter-item correlations	Standard errors of alpha	Item-rest correlations	Alpha if item deleted
Worry	0.68	0.0038	0.76	0.75
Interrupt	0.69	0.0036	0.70	0.67
Clothes	0.67	0.0040	0.84	0.82
Plans	0.67	0.0039	0.83	0.80
Food	0.67	0.0040	0.84	0.82
Hands	0.67	0.0040	0.84	0.82
Body	0.66	0.0041	0.87	0.85
Drink	0.67	0.0040	0.86	0.84
Angry	0.66	0.0041	0.89	0.87
Sleep	0.67	0.0040	0.83	0.81
None	0.68	0.0037	0.75	0.72
Shame	0.66	0.0041	0.88	0.86

3.5.Validity of the Adapted HWISE Scale

The adapted scale demonstrated convergent validity. A moderately inverse significant association between the HWISE scores and 24 hour water intake ($\rho = -0.480$, $p < 0.001$) correlates reduced water consumption with higher water insecurity experience scores. Likewise, a significantly large correlation was observed between water insecurity experiences scores and time spent fetching water ($\rho = 0.549$, $p < 0.001$), another external validity shown by the adapted scale. Moreover, positive significant correlation was found between the cost of water and water insecurity experiences ($\rho = 0.549$, $p < 0.001$), highlighting their direct relationship.

The Mann-Whitney U test statistic water was used to compare the mean rank of water insecurity experience scores between groups (Table 9). Significantly ($p = 0.031$) higher water insecurity

experiences were observed among women history of a water collection injury ($n = 112$, mean rank = 144.27) compared to women with no such history ($n = 152$, mean rank = 123.83). The mean rank of water insecurity score was significantly higher (U statistic = 7218.500, $p = .024$) among households that access unimproved water sources ($n = 146$, mean rank = 142.06) compared to households accessing improved sources ($n = 118$, mean rank = 120.67). The Mann-Whitney U test (U statistic = 3714.500, $p < 0.001$) further revealed a significantly higher mean rank in water insecurity scores among households with childhood diarrheal disease ($n = 55$, mean rank = 169.46) compared to households without recent illness ($n = 209$, mean rank = 122.77).

Table 9 Discriminant validity for the adapted HWISE scale

Variable	Ranks							
HWISE score	Mean rank	Sum of Ranks	Mean rank	Sum of Ranks	Mann-Whitney U	Wilcoxon W	Z-test	p-value
Injury related with water fetching								
	Yes (n = 112)		No (n = 152)					
	144.27	16158.00	123.83	18822.00	7194.000	18822.000	-2.151	0.031
Type of main water sources								
	Unimproved (n = 146)		Improved (n = 118)					
	142.06	20740.50	120.67	14239.50	7218.500	14239.500	-2.264	0.024
History of diarrhea among under-five children								
	No (n = 209)		Yes (n = 55)					
	122.77	25659.50	169.46	9320.50	3714.500	25659.500	-4.038	< 0.001

4. Discussion

This study sought to culturally adapt and evaluate the psychometric properties of the Sidaamu Afoo HWISE scale, while recognizing women as those most aware of water insecurity's impact. Following implementation guidelines [62], cultural adaptation of the HWISE scale adhered to a multi-step methodological framework to tailor a linguistically equivalent and comprehensible scale [25]. The original HWISE scale underwent forward and backward translations. Two independent forward translations were reviewed then synthesized into an integrated version. Back translation was carried out by a second independent and bilingual expert. Once a consensus was reached, the pre-final version was generated prior to undergoing a robust examination of the content validity.

Recommended psychometric protocols [27] were used to evaluate the scale's content validity. Relevance of each item to their respective domain was rated by experts with the appropriate educational and experiential background. The I-CVI and S-CVI values surpassed the recommended thresholds of 0.7 and 0.80, respectively, ensuring rigorous content validation [25]. This indicated as the linguistic translations and semantic equivalence were maintained while ensuring comprehensiveness and enhancing fidelity of the scale [27].

Given that 4-point Likert-type ordinal responses (never = 0; rarely = 1; sometimes = 2; and often/always = 3) failed to meet the assumption of normality. Retention of the dominant factor was based on the Horn's Parallel Analysis and consistent with psychometric mythological recommendations [50]. As such, the measured items were contained into a single underlying construct, signifying that the adapted HWISE scale was unidimensional. In addition to the current scale's sufficient explained variance confirmed unidimensional structure.

Strong loadings of the items confirmed this, with none of the items loaded below the minimum thresholds of ≥ 0.3 . Findings from this study align with similar work from LMICs [11,13,17] and the original HWISE scale already validated across cultures and ecologies [10].

The CTT framework was used to estimate the adapted HWISE scale's reliability, modeling the individuals' observed score as the summation of a true value and random error attributed to the

measurement. Underlying constructs demonstrated strong internal consistency reliability, measured by coefficient of ordinal α . Accordingly, α values of 0.96 (95% CI [0.92, 0.99]) presented 4% contamination (the lower bound of the estimate); meanwhile, the adapted scale demonstrated 96 % reliable to quantify household water insecurity experiences during the previous 4-week interval. Furthermore, item equivalence of the underlying construct was observed. Psychometric literature suggest that the higher the true scores (i.e., the degree to which true score is measured), the lower the risk of committing measurement error [35].

In comparison with other treatments of the HWISE scale, the reliability coefficient was different and the strength of the internal consistency was consistent [10,17,63]. Together these suggest internal consistency reliability of the adapted HWISE scale. The Likert-response options presented for the HWISE scale has only four options, which limits the use of Cronbach's alpha (α), biasing the estimator. This issue was addressed in through this work, using robust parameter estimations that account for the ordinal nature of the given data. Effectively, ordinal coefficients of α , a reliability estimate for PCM [20] were estimated here.

5. Conclusion

The adapted HWISE scale demonstrates a unidimensional factor structure that explains 67.6% of the observed variance. The scale showed strong content and construct validity. Its excellent reliability further confirmed the adapted scale's rigor in capturing the multifaceted household water insecurity experiences among the Sidaamu Afoo speakers in Ethiopia. As such, the current scale can be used to evaluate local water supply intervention programs evaluations. Future studies should recruit diverse study participants and further address seasonal variations.

6. Acknowledgments

We are thankful to the residents of the HZD for their participation in this study. We are grateful to Sera L. Young, the lead author of the original HWISE scale for granting permission to adapt the scale for the Ethiopian context. We also extend our acknowledgement to Alexandra Brewis and Israël Zaldívar for reviewing the manuscript support, and Getahun Solomon for assistance during statistical analysis. My wife (Marigarita Mathewos), translators, content validity rating experts, data collection team and all study participants are acknowledged for their immense contributions.

7. Abbreviations

CVI = Content Validity Index; CTT = Classical Test Theory; EFA = Exploratory Factor Analysis; HWISE = Household water insecurity Experiences; ICC = Intraclass correlation coefficient; KMO = Kaiser-Meyer-Olkin;

8. Conflict of interest

We, the authors, declare no conflict of interest.

9. Authors contribution

AE: responsible for designing the study, coordination, methodology, statistical analysis, and drafted the manuscript. BM, SRG and AA: responsible for the methodological framing. All authors took part in reviewing, editing, and final approving approval of this manuscript.

10.Data availability

All authors approved the final manuscript. This final manuscript included the dataset used is presented with different forms. Additional raw data can be availed based on the reasonable request.

11. Funding

No funding was secured for this study.

12.Consent to participation

Obtained from every study participants.

13.Reference

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