Investigating the suitability of dichotomous responses for the Water Insecurity Experience (WISE) Scales using nationally representative data from 39 countries

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Abstract

Background

The Water Insecurity Experiences (WISE) Scales have been validated to comparably measure water insecurity globally. The scales consist of 12 items that can be administered in approximately 3 minutes. There is interest in developing more rapid WISE Scale versions, for use when time is limited. One alternative is to use a subset of 4 items, which has been validated, but has some drawbacks. Here we investigate another alternative: dichotomous (yes/no) response options instead of the original four levels of frequency-based (polytomous) responses.

Methods/principle findings.

We used nationally representative data from 39 countries to simulate dichotomized responses by collapsing the four levels of frequency (never, rarely, sometimes, often/always) into yes/no. We first explored if "rarely" is meaningful in the gradation of water insecurity, as experiences that occur "rarely" may not be affirmed with dichotomous response options. We tested item-by-item if "rarely" responses predicted dissatisfaction with water quality using logistic regression and found that they were associated with higher odds of dissatisfaction with water quality. As such, some meaningful nuance may be lost if "rare" experiences are not affirmed as "yes".

We then compared the predictive accuracy of WISE scores using simulated dichotomous responses vs. those calculated using polytomous responses. Based on ROC curves and regression models, dichotomized response scores had good predictive accuracy. Scores calculated using the abbreviated 4-item version were also found to be similarly accurate. Finally, we explored if it was possible to determine levels of water insecurity that were comparable to the levels calculated using the original responses using dichotomized responses. Using ROC curves, we found that it was possible, which is an advantage over the 4-item scales.

Conclusion/significance

Although polytomous responses options provide more information, dichotomous response options hold promise as a quicker alternative for measuring water insecurity.

Introduction

Water insecurity, the inability to reliably access sufficient water for basic domestic needs, is of increasing global concern given its negative effects on health and well-being. Accurate and reliable measurement of water insecurity is critical for identifying affected and vulnerable populations, developing policies and programs to reduce its burden, and advancing progress toward Sustainable Development Goal 6, ensuring access to safe water for all (1-4).

The Water Insecurity Experiences (WISE) Scales comparably measure experiences with issues with reliable access and use of water for basic domestic needs across countries (5). The Scales comprise 12 questions that can be used for assessments at the household (the HWISE Scale) (3) and individual level (the IWISE Scale) (6); they take approximately 3 minutes to administer (5). The WISE scales complement existing “provider-side” water indicators (e.g., access to safely managed drinking water services using WHO/UNICEF’s Joint Monitoring Programme’s criteria (7)) by capturing the state of people’s water insecurity (8). That is, they offer “user-side” perspectives on experiences accessing and using water for consumption, hygiene, and other basic activities. In recognition of the added value of these scales to existing measures, they are increasingly being adopted by governments and development organizations to inform policy and practice and to monitor and evaluate the impact of water-related programs (5, 9-11).

In the original versions of the HWISE and IWISE Scales, item responses measured not only if each of the 12 water-related issues was experienced, but also the frequency (“never”, “rarely”, “sometimes”, or “often/aways”) with which they were experienced in a specified recall period (**Figure 1**). For example, “rarely” refers to an experience occurring on 1-2 days over a 4 week recall period or in 1-2 months over a 12-month recall period (**Figure 1**). Each response is scored 0-3; the sum of the item responses can then be used to classify individuals or households as experiencing no-to-marginal, low, moderate, or high water insecurity (12).

Figure 1. *The items in the Water Insecurity Experiences (WISE) Scales ask about adverse experiences caused by problems with water, represented by these 12 icons and labels. Twelve items take approximately 3 minutes to administer. The four items on the top row are those that comprise the abbreviated versions and take one minute to administer. Full phrasing is in Supplemental Table 1. Figure reproduced from a prior publication (13).*

Note: Polytomous response options are “Never”, “Rarely”, “Sometimes”, “Often/Always”; dichotomized response options are “No” or “Yes”.

Academics, as well as those in governmental and non-governmental organizations working with constrained budgets or rapid assessments, have expressed interest in developing versions of WISE scales that are quicker to implement and reduce participant burden. To that end, abbreviated versions of the WISE scales – the HWISE-4 (14) and IWISE-4 (13) Scales – which are composed of a subset of four items and take only one minute to administer, have been developed and validated in low- and middle-income countries (13, 14) (**Figure 1**). In March 2024, the IWISE-4 Scale was recommended by WHO/UNICEF’s Joint Monitoring Programme for generating gender-disaggregated indicators to monitor global progress toward Sustainable Development Goal 6 (15).

Although the 4-item WISE Scales have practical benefits, they are limited in two important ways. First, because they only query four experiences, they may not capture key experiences of water insecurity in some settings. For instance, water interruptions were the most commonly reported item by respondents to the 2022 Gallup World Poll in Australia and the United States (16), but “interruptions” is not an item included in the abbreviated scales. Second, these abbreviated scales do not generate enough information to assess multiple categories of water insecurity. That is, the 4-item WISE Scales can only categorize individuals or households as experiencing water insecurity, or not, and are not well-suited to measure different severity levels along the spectrum. Given the global heterogeneity in

experiences of water insecurity and the effects that even low levels of water insecurity can have on health and well-being, the ability to classify individuals into multiple categories of water insecurity using the 12 WISE items has practical utility (12).

Dichotomous Response Options: An Alternative for Rapid Assessment

Given the limitations of the 4-item WISE Scales, there is interest in investigating other strategies for measuring water insecurity experiences efficiently while maintaining validity for situations in which rapid data collection and limited resources are key concerns. One such strategy is using dichotomous response options, whereby respondents report whether they ever experienced any of the issues (i.e., “yes” or “no”) within a particular recall period. Dichotomous responses with experience-based food-insecurity scales have been used at the national, regional, and global level for decades (17-19). In Brazil, for example, the Brazilian Scale of Food Insecurity has been useful for identifying categories of food insecurity, enabling policymakers and program designers to address the distinct causes and solutions associated with each severity category (20).

Scales with dichotomous response options offer several potential advantages over those with polytomous levels (e.g., never/rarely/sometimes/often). They may be quicker to administer and therefore less costly, making them more feasible when budget and time are limited. For example, a study in Mexico found that prompting with dichotomous response options on the HWISE scale reduced the time to administer the scale from three to two minutes (21). The reason for this may be that dichotomous response options reduce the cognitive burden on respondents and enumerators; respondents are not required to recall the exact frequency of each experience and prompting by enumerators can be reduced. Furthermore, dichotomous responses can be more stable than polytomous responses when assessing a scale’s psychometric properties and equating it across countries using Rasch models (22), the current modeling approach used with the Food Insecurity Experience Scale (FIES) across countries worldwide to track progress toward Sustainable Development Goal

target 2.1 (23, 24). For instance, if responses of “rarely” are less frequent than responses of “sometimes”, this can lead to disordered thresholds (i.e., severity levels that do not increase monotonically across response categories) in a Rasch rating (or partial credit) model, hindering the interpretation of the construct frequency(25, 26). One solution to this is to collapse response categories, but it is preferrable to present response options to participants that avoid these issues altogether.

Despite these potential advantages, the use of dichotomous response options has been questioned in other contexts, such as when measuring anxiety related to health and in scales measuring attitudes and opinions (27, 28). There are concerns that a dichotomized format of responses in scales discriminate less well between degrees of the construct of interest (e.g., varying severity and frequency of experiencing anxiety). Furthermore, it is unclear how respondents will answer when they have fewer response options, especially if they only occasionally experience the condition under question. When offered only dichotomous options, some might not consider an experience that occurred infrequently to merit affirmation (i.e., they might respond “no/never” when the experience only occurred rarely, e.g., once or twice). Therefore, despite dichotomous response options potentially reducing complexity and respondent burden, they may compromise the scale's sensitivity to varying frequencies of water insecurity experiences. This trade-off must be critically evaluated in diverse settings.

Considering these potential advantages and disadvantages, it is uncertain how accurately the WISE Scales with dichotomous responses would capture experiences of water insecurity. Therefore, we sought to understand the potential consequences of using dichotomous responses rather than polytomous response options for the WISE Scales. Because the WISE scales have thus far primarily been administered using polytomous response options, we addressed this goal by simulating dichotomous responses. We used two dichotomization scenarios to account for any potential uncertainty around how people

who responded "rarely" to any of these experiences may respond when given a dichotomous option. We used nationally representative datasets from 39 countries in which the 12-item WISE Scales had been administered. Specifically, we sought to answer four questions:

1. Are "rarely" responses affirmed frequently enough to be meaningful in the calculation of water insecurity experience scores?
2. Can 12-item WISE scores calculated using simulated dichotomous responses accurately predict scores calculated using (the original) polytomous responses?
3. How does the predictive accuracy of the 12-item WISE Scales using simulated dichotomous responses compare to that of the 4-item WISE Scales using polytomous responses?
4. Is it possible to create four ordinal categories of water insecurity using simulated dichotomous responses to the 12-item WISE scales that distinguish between levels of water insecurity severity as well as the categories made using the original scoring?

Methods

Study design, population, and key variables

This analysis used nationally representative datasets from two sources: IWISE data from the 2020 and 2022 Gallup World Poll (GWP) (29, 30) and HWISE data from the 2021 Mexican National Health and Nutrition Survey (ENSANUT 2021) (31). GWP implemented the IWISE Scale with a 12-month recall period among individuals aged 15 years and older across 31 countries between September 2020 and February 2021 (30), and a further 7 countries in 2022 (n=50,768). The methodology for data collection and obtaining informed consent from participants followed Gallup's established protocols, which have been detailed elsewhere (6, 29) and approved by governing bodies as required in each country. ENSANUT 2021 surveyed 12,463 households, with a recall period of 4 weeks. Full details on the ENSANUT survey methodology and nationally representative sampling strategy have been described elsewhere (31). ENSANUT participants provided written informed consent.

GWP surveys included the WISE Scales and an item about water quality dissatisfaction. The WISE Scales ask about 12 experiences related to problems with water, including modified or limited behaviours (e.g., unable to wash hands), psychosocial impacts (e.g. worry about water), and supply interruptions (Figure 1, full phrasing in Supplementary Table S1). Respondents were asked to report how frequently they (when the IWISE Scale was used) or anyone in their household (when the HWISE Scale was used) experienced these issues. Data were collected with response options “never” (scored as 0), “rarely” (1), “sometimes” (2), and “often” or “always” (3).

Dissatisfaction with water quality, a measure previously used to assess the construct validity of the IWISE-12 scale (6), was measured with the item “In your city or area where you live, are you satisfied or dissatisfied with the quality of water?”. Participants responded either “satisfied” or “dissatisfied” that was coded as binary variable: (disatisifed-1; satisfied-0).

Calculating WISE scores and categories using the 12-item scales with polytomous response options

WISE Scale responses are summed to create a score with a possible range of 0 to 36, with higher scores indicating greater water insecurity. Cut-points have been established to classify individuals and households as experiencing four levels of water insecurity: “no-to-marginal” (scores of 0-2), “low” (3-11), “moderate” (12-23), or “high” water insecurity (24-36) (6, 12).

Calculating WISE scores using the 12-item scales with dichotomized response options: two scenarios

Using the data from the polytomous scales described above, we simulated dichotomised responses (i.e., participants affirming whether the experience occurred during the given recall period or not). We simulated two potential scenarios. In the first scenario, termed “Any

Affirmation," any affirmative response ("rarely," "sometimes," "often", or "always") was recoded as "yes" (1), and "never" was recoded as "no" (0). Given the aforementioned uncertainty about how individuals who responded "rarely" to an experience may answer questions with dichotomous responses, we simulated a second scenario. In the second scenario, termed "Sometimes-to-Always Affirmation", "sometimes", "often", and "always" were recoded as "yes" (1), whereas "rarely" and "never" were recoded as "no" (0). The resulting summed scores for both versions ranged from 0 to 12.

Calculating WISE scores and categories using the 4-item scales with polytomous responses

The abbreviated 4-item versions of the IWISE and HWISE Scales, referred to as IWISE-4 (13) and HWISE-4 (14), respectively, include a subset of four of the 12 experiences asked about in the full versions: worrying about not having enough water, not being able to wash hands after dirty activities due to problems with water, not having enough water to drink, and having to change plans due to problems with water (Figure 1). These responses are summed to create overall water insecurity scores; these can range from 0-12. A score of ≥4 has been used as a cut-point to categorize individuals or households as experiencing water insecurity (13, 14).

Statistical analysis using IWISE data

For our first question (if "rarely" responses are affirmed sufficiently frequently to be meaningful in the gradation of water insecurity), we plotted the response frequency for each experience across all countries in the Gallup World Poll. To identify potential differences in the frequency of affirming "rarely" by national water insecurity burden, we also plotted the frequency among countries with low (i.e., United States, Australia) and high (i.e., Cameroon, Zambia) national prevalence of water insecurity. We then used multiple logistic regression models, adjusted for country, to test whether responding "rarely" to an experience was associated with self-reported dissatisfaction with one's water quality.

For our second question (the predictive accuracy of simulated dichotomous WISE responses to the 12-item scales, relative to those with polytomous responses), we conducted four sets of analyses. First, we used linear regression models to regress the scores from polytomous response options on the scores from dichotomised response options. In these models, we estimated root mean squared errors (RMSE) to quantify the magnitude of error due to dichotomising responses. These models were estimated separately for each country, and the average and ranges across countries were calculated

Second, we constructed receiver operator characteristic (ROC) curves to evaluate the sensitivity and specificity of different cut-points for scores calculated using dichotomized responses in relation to moderate-to-high water insecurity, as classified using scores generated from the original scale with polytomous responses. We then examined the areas under the curve (AUC) to understand the accuracy of the scores calculated using the two dichotomous scenarios ("Any Affirmation" and "Sometimes-to-Always Affirmation").

Third, we calculated the simulated weighted prevalence of moderate-to-high water insecurity using the optimal cut-points identified by the ROC curves and compared these to the estimated prevalence when using scores generated from polytomous responses. For each country, we estimated the absolute percentage-point differences in prevalence estimates, the percentage of people correctly classified, and the AUC.

Finally, we used logistic regression to compare how scores generated from dichotomized and polytomous responses predicted water quality dissatisfaction. We compared a 3-point difference in the scores from polytomous to a 1-point difference in the dichotomized responses versions. We examined the AUC to compare the accuracy of the polytomous compared to the dichotomized versions. We also ran logistic regressions using the optimal cut-points identified by the ROC curves for dichotomized versions, and a cut-point of ≥12 for

the polytomous version to examine how these definitions of moderate-to-high water insecurity were associated with the odds of water quality dissatisfaction.

For our third question (about the predictive accuracy of the WISE Scales using dichotomized responses compared to that of the 4-item WISE Scales using polytomous responses), we ran linear regressions to test the association between scores from the 12-item scales (using polytomous and dichotomous responses) and scores from the 4-item scale with polytomous responses. We calculated RMSE and residuals to quantify prediction errors. Additionally, we calculated the weighted prevalence of moderate-to-high water insecurity using a cut-point of ≥4 for the 4-item scale (13) and compared it to that estimated using the original 12-item scale. We then used logistic regression to understand if water insecurity, as classified using the four different versions of the tool, was associated with water quality dissatisfaction, which was used to assess the construct validity of the IWISE-12 scale (6).

For our fourth question (if it is possible to calculate 4 levels of water insecurity using scores generated from dichotomized response options), we used ROC curves to determine whether cut-points in scores from the dichotomous responses could be identified. Specifically, we tried to determine if we could identify cut-points with high sensitivity and specificity for each water insecurity category, as calculated using scores from the full scale with polytomous responses.

Sensitivity analysis using HWISE data

To assess whether the answers to our four research questions differed when using household-level observations, we repeated these analyses with data from ENSANUT 2021, which is, to our knowledge, the only survey vehicle through which nationally representative HWISE data have been collected. A total of 12,619 households were interviewed using the HWISE module, of which 156 households were missing responses to one or more WISE

experiences. These households were excluded from the analysis, resulting in a final sample of 12,463 households.

Associations between WISE scores calculated using dichotomized compared to polytomous response were estimated using linear regression. We used ROC curves to explore cut-points in the scores generated from dichotomized responses that maximized sensitivity and specificity for classifying moderate-to-high water insecurity, as determined using WISE scores from polytomous responses (3). Prevalence estimates (unweighted) of moderate-to-high household water insecurity, as assessed using the identified optimal cut-points for the scores calculated with dichotomous responses, were compared to that estimated using scores calculated with polytomous responses. A question about water quality satisfaction was not asked in this survey.

Ethics

This study using secondary, deidentified data was determined to not constitute human subjects research by the Institutional Review Board at the University of North Carolina at Chapel Hill. Gallup World Poll survey procedures were approved by governing bodies as required in each country. Gallup obtained informed consent from participants. We received deidentified data from Gallup for our analyses. All ENSANUT survey procedures were reviewed and approved by the Research, Biosecurity, and Ethics Committees of the National Institute of Public Health, Mexico. Each respondent to the household survey provided his or her written informed consent (Project ID: 1750).

Results

The IWISE Scale was administered to 52,560 individuals in 38 countries through the Gallup World Poll. Of these, 1,792 (3.4%) were missing values to one or more experiences and excluded from the analysis using the full scores, resulting in a final sample of 50,768 individuals.

The contribution of "rarely" to WISE scores (Question 1)

"Rarely" was a common response to each experience **(Figure 2A)**. For each item, between 32% and 37% of respondents who affirmed an experience reported it as occurring "rarely" (**Supplementary Table S2**). In countries with a low prevalence of moderate-to-severe water insecurity, such as Australia (A, 0.973%) and the US (U, 3.67%), "rarely" accounts for most of the affirmations (**Figure 2B**). In Australia, between 52% to 93% of respondents who affirmed an experience reported it as occurring "rarely", compared to between 58% and 79% in the United States (Supplementary Table S2). Conversely, for countries experiencing a high national prevalence of moderate-to-high water insecurity, such as Cameroon (C, 63.9%) and Zambia (Z, 48.1%), "rarely" was affirmed less frequently (**Figure 2C)**. In Cameroon, between 19% to 27% of respondents affirming each experience reported it as occurring "rarely", compared to 23% to 29% in Zambia (Supplementary Table S2).

In logistic regression for each WISE item, the odds of reporting water quality dissatisfaction increased monotonically across polytomous options (**Table 1**). The odds of reporting water quality dissatisfaction were higher among those who responded "rarely" compared to those who responded "never" experiencing a given issue. These results suggest that rare occurrences of water issues can meaningfully predict other constructs related to water insecurity.

Figure 2. *Distribution of responses to water insecurity experiences (unweighted) in nationally representative data from 38 countries (n= 50,768, Gallup World Poll 2020, 2023). A: Aggregated across countries. B: Distribution of "rarely" responses in countries with a relatively low prevalence of moderate-to-high water insecurity (Australia (A) 0.973%; USA (U) 3.67%). C: Distribution of "rarely" responses in countries with a relatively high prevalence of moderate-to-high water insecurity (Cameroon (C) 63.9%; Zambia (Z) 48.1%).*

Table 1. *Odds of reporting water quality dissatisfaction in relation to the reported frequency of experiencing each WISE item (weighted and adjusted for country) using nationally representative data from 38 countries (n= 50,768, Gallup World Poll 2020, 2022).**

**Reference for all models was "Never".*

The predictive accuracy of scores calculated using dichotomized responses (Questions 2 & 3)

Both versions of the dichotomised-response scores – "Any Affirmation" and "Sometimes-to-Always Affirmation" – accurately predicted scores calculated using the 12-item IWISE Scale with polytomous responses (**Table 2**; see Supplementary Tables S3A and S3B for country-specific results).

The RMSE (i.e., the standard deviation of the residuals from the regression model) was lower for the "Sometimes-to-Always Affirmation" version compared to the "Any Affirmation" version, indicating better overall predictive accuracy of the former. There was, however, greater variability of the residuals at higher values of the "Sometimes-to-Always Affirmation" version, whereas the variability of the residuals appeared to be even across values of the "Any Affirmation" (Supplementary Figure S1); both exhibited heteroskedasticity. The residual pattern and RMSE of the 4-item IWISE Scale were similar to that of the " Sometimes-to-Always Affirmation" version (**Table 2**; see Supplementary Table S3C for country-level results). The mean beta coefficient from the models regressing the polytomous score on the dichotomized scores was highest for the IWISE-4 Scale (2.65, range: 2.24-2.84) and lowest for the "Any Affirmation" version (1.95, range: 1.39-2.26). The " Sometimes-to-Always Affirmation" version showed a slightly higher mean beta value of 2.35, ranging from 2.13 to 2.60 across countries. The IWISE-4 scale had the highest mean beta value of 2.68, ranging from 2.24 to 2.84 across countries. Despite these differences, the R-squared values, correlation coefficients, and standard errors were similar across both dichotomized versions

and IWISE-4. In short, both dichotomized versions and IWISE-4 had similar predictive accuracy.

Table 2. Unweighted linear regression of the 12-item IWISE Scale (using polytomous responses) on simulated IWISE scores (using two strategies for dichotomizing responses, "Any Affirmation" and "Sometimes-to-Always Affirmation") and scores from the 4-item IWISE Scale, averaged across 38 countries (n=50,768*, Gallup World Poll 2020, 2022)
**Per country N Mean=980; Median=1336; Range= 878-12349; **RMSE: Root Mean Squared Error.*

The AUC for scores calculated using both versions of dichotomization showed high accuracy, with values close to 0.98 (Supplementary Figure S2). This indicates that both versions were accurate at predicting moderate-to-high water insecurity, as defined as scores ≥12 in the original 12-item scale with polytomous responses.

For the "Sometimes-to-Always Affirmation" dichotomised version, cut-points of ≥4 and ≥5 resulted in the highest overall correct classification of moderate-to-high water insecurity, at 94% and 95%, respectively (Supplementary Tables S4A and S4B). For the "Any Affirmation" dichotomised version, greater accuracy was achieved with higher cut-points (≥6 and ≥7), although a high percentage were correctly classified when using a cut-point of ≥4 (86%) and ≥5 (90%). Country-specific details on the percentage correctly classified and AUC for both versions are available in Supplementary Tables S5A and S5B.

We identified different cut-points for estimating water insecurity prevalence using the two dichotomized versions (**Figure 3**). A cut-point of ≥4 in the "Sometimes-to-Always Affirmation" version provided an estimate of water insecurity prevalence that was 2 percentage points higher than the estimate from polytomous responses, whereas that same cut-point in the "Any-Affirmation" version resulted, on average, in a 16 percentage-point over-estimation

(**Figure 3**). In contrast, a cut-point of ≥7 for "Any-Affirmation" resulted in a 1 percentage-point over-estimation of water insecurity prevalence but a 12 percentage-point under-estimation of water insecurity prevalence using the "Sometimes-to-Always Affirmation" version. (Tables S6A and S6B in the supplementary files show the weighted prevalence estimates per cut-point for each country.) By comparison, using a cut-point of ≥4 for IWISE-4 (which has been previously validated), resulted in an average 3-percentage-point overestimation (Supplementary Table S6C). Therefore, while similar prevalences can be estimated using both dichotomized versions, the cut-points will differ depending on whether response patterns with dichotomous options align more closely with the simulated "Any Affirmation" version or "Sometimes-to-Always Affirmation" version.

Figure 3. *Average absolute differences in prevalence estimates of moderate-to-high water insecurity, comparing the estimated prevalence from the 12-item scale with polytomous responses to those estimated using various cut-points with the "Any Affirmation" and "Sometimes-to-Always Affirmation" versions (weighted), based on nationally representative data from 38 countries (n= 50,768, Gallup World Poll 2020, 2023).*

The associations between dichotomised-response IWISE scores and odds of reporting water quality dissatisfaction **(Figure 4)** were similar for both the "Any Affirmation" (red line) and " Sometimes-to-Always affirmation" (green line) scenarios compared to that observed when using polytomous responses (blue line). The 4-item IWISE Scale (yellow line) had comparable associations, demonstrating the consistency of these results across different scoring methods. Similar AUC values suggests that both dichotomized versions and IWISE-4 had comparable accuracy to the original 12-item scale with polytomous responses in predicting dissatisfaction with water quality. In other words, the abbreviated scales behaved similarly to the full scale in predicting another construct related to water insecurity.

Figure 4. *Predicted probability of reporting dissatisfaction with water quality by each IWISE response score option. Score options include the full IWISE Scale using polytomous responses (at 3-point intervals), the full IWISE Scale using dichotomized responses ("Any Affirmation" and "Sometimes-to-Always Affirmation" version), and the 4-item IWISE Scale using polytomous responses, based on nationally representative data from 38 countries (n= 50,768, Gallup World Poll 2020, 2022).**

**All models were adjusted for country and weighted by survey weights. For the full IWISE12 score with polytomous items, the range was 0 to 36 (i.e., each point as labeled on the x-axis corresponds to 3 points on the full IWISE12 polytomous item score)*

When using various cut-points (≥4, ≥5, ≥6, and ≥7) to define moderate-to-high water insecurity, both dichotomized versions yielded odds of reporting water quality dissatisfaction that were similar to those obtained when using a cut-point of ≥12 for the full scale with polytomous responses (Supplementary Table S7). For example, for individuals experiencing moderate-to-high water insecurity, as classified using the full scale with polytomous responses, the odds of water quality dissatisfaction were 4.5 times higher (95% CI: 4.18-4.85) compared to those experiencing no-to-low water insecurity. In comparison, the estimated odds for the "Any-Affirmation" version at a cut-point of ≥5 was 4.28 (95% CI: 3.99-4.58) and 4.11 (95% CI: 3.81-4.44) for the same cut-point using the "Sometimes-to-Always affirmation" version. At higher cut-points, similar associations were observed, although the strength of associations tended to decrease as the cut-points increased. The IWISE-4 scale, using a cut-point of ≥4, had a comparable association with water quality dissatisfaction (OR: 4.29, 95% CI: 3.99-4.61). These results indicate that all scoring versions exhibited similar construct validity.

Creating water insecurity categories with dichotomized responses (Question 4)

Using ROC curves, we identified cut-points that enabled the categorization of water insecurity for both dichotomized versions ("Any" " and "Sometimes-to-Always" affirmations).

These cut-points resulted in similar distributions of individuals across water insecurity categories (no-to-marginal, low, moderate, and high) when compared to the 12-item scale with polytomous responses (**Figure 5**). Thus, it was possible to estimate ordinal water insecurity categories using both dichotomized versions. (Supplementary Tables S8A-S9B provide details on the proportion of individuals correctly classified at each cut-point, as well as the AUC values for countries with low and high overall water insecurity.)

These results demonstrate the feasibility of categorizing water insecurity using scores calculated with dichotomous response options. We cannot propose definitive cut-offs, however, because the current analysis relies on simulated data. Establishing appropriate cut-offs requires empirical data that capture how individuals respond when the items are explicitly presented with dichotomous response options.

Figure 5. *Proportion of individuals classified within each level of water insecurity based on the validated cut-offs for the original 12-item IWISE Scale with polytomous responses, and the cut-offs identified for the dichotomized versions ("Any-Affirmation" and "Sometimes-to-Always affirmation") based on nationally representative data from 38 countries (n= 50,768, Gallup World Poll 2020, 2022).*

Sensitivity analyses using HWISE data

We observed similar relationships using HWISE data collected in the ENSANUT survey in Mexico (Supplementary Text 1, Supplementary Tables S10-S13, Supplementary Figures S3-S5).

Discussion

We evaluated whether experiencing issues with water access and use only rarely was associated with other water problems (e.g., dissatisfaction with water quality) and simulated the potential consequences of administering WISE scales with dichotomous instead of polytomous responses using data from nationally representative surveys in 39 countries (see

505 **Table 3**). First, even a rare experience of any of the 12 WISE items was strongly associated
506 with higher odds of also reporting dissatisfaction with water quality. Second, two scenarios
507 for dichotomizing polytomous items (either considering rare experiences as an affirmation or
508 not) were simulated. Both dichotomization scenarios accurately predicted the 12-item scale
509 score calculated using polytomous responses. Third, the predictive accuracies of the 12-item
510 scale with dichotomized responses were similar to the predictive accuracy of the abbreviated
511 IWISE-4. Fourth, estimation of low, moderate, and high water-insecurity categories was
512 reasonable with both versions of the dichotomized WISE scales. Taken together, these
513 findings suggest that administering the WISE scales with dichotomous instead of polytomous
514 response options may be a useful strategy in some situations, but it may come at the cost of
515 some lost information, as discussed below.
516
517 **Table 3. Summary of research questions, analyses performed, and results**
518
519 Given the importance of even "rare" experiences in the gradation of water insecurity
520 experiences, the interpretation of water insecurity may be affected if rare occurrences are
521 not adequately captured when items are administered with dichotomous response options
522 (i.e., if respondents chose not to affirm an experience that occurred only once or twice).
523 Thus, when administering the WISE Scales with dichotomous response options, efforts
524 should be made to encourage respondents to carefully consider if these experiences have
525 occurred even once over the recall period, and if so, to affirm these experiences, so as not to
526 miss people who are experiencing infrequent water insecurity. That is, instructions must
527 clarify that any occurrence should be considered an affirmation.
528
529 Dichotomous response options may limit the ability to understand water insecurity dynamics
530 in some situations. For example, an intervention may cause people to shift from
531 experiencing an issue often to rarely, as has been found for food insecurity (32). This

532 difference is meaningful for understanding the impact of an intervention but would be lost if
533 only dichotomous response options were provided. We therefore recommend polytomous
534 response options that capture the frequency of experience for program evaluations.
535 Similarly, understanding the frequency with which these experiences occur might be
536 important for designing effective targeted strategies, as those experiences issues more
537 frequently may require a different level of intervention, understanding frequency of food
538 insecurity coping strategies has been shown to be useful to inform targeting of food security
539 interventions (33).
540
541 Both versions of simulated dichotomized responses (i.e., whether rare experiences were
542 considered an affirmation or not) accurately predicted IWISE and HWISE scores calculated
543 using the polytomous response options. The scores from dichotomized responses also had
544 similar accuracy in predicting a related construct of water insecurity (dissatisfaction with
545 water quality). The WISE-4 has similar predictive accuracy to the dichotomized scores, both
546 in terms of predicting scores calculated from WISE-12 polytomous responses and predicting
547 a related water insecurity construct. While both abbreviated versions of the scales (WISE-4
548 and WISE-12 with dichotomous responses) may offer viable alternatives to the full scale
549 when time and resources are limited, the 12-item WISE scales with dichotomous responses
550 will better capture the full array of ways in which water insecurity can manifest and interrupt
551 life.
552
553 The prevalence of no-to-marginal, low, moderate, and high water insecurity could be
554 estimated using WISE scores with dichotomized responses, providing a clear advantage
555 over the abbreviated IWISE-4 and HWISE-4 Scales. What those cut-points are, however, will
556 depend on how participants respond when offered dichotomous response options. For
557 IWISE, if all respondents who responded “rarely” were considered to have affirmed the
558 experience (the “Any Affirmation” scenario), then a cut-point of $\geq$7 has the best specificity
559 and a cut-point of $\geq$6 has the best sensitivity for classifying moderate-to high water

insecurity. If, however, those who responded "rarely" were not to have not affirmed the experience (the "Sometimes-to-Always Affirmation" scenario), then a cut-point of ≥5 has the best specificity and a cut-point of ≥ 4 has the best sensitivity for classifying moderate-to high water insecurity. Ultimately, the establishment of appropriate thresholds for defining different levels of water insecurity with WISE scales scores with dichotomized responses must be based on data from WISE surveys administered with this response format from the start.

A challenge in knowing which of the versions of simulated dichotomized responses best illustrates the amount of information lost when administering WISE surveys with dichotomized responses is that we do not know how people would have responded if they had been presented with a dichotomous response option. Research is needed in which dichotomous responses are presented to the respondent, ideally in direct comparison using a split sample to the presentation of polytomous responses. One such split-sample study has been conducted in Mexico with HWISE-12; this study found that the prevalences of water insecurity estimated in the sub-sample that was administered the survey with dichotomous response options was comparable to the prevalence of the sub-sample that was administered the survey with polytomous response options (21).

Further research is required to understand how affirmations might change depending on many response options are presented and whether prompts are provided to encourage respondents to consider rare occurrences as an affirmation. Further research is also required to understand how respondents' affirmation of items that occur only rarely might change when presented with dichotomous (experienced the issue or not) instead of a polytomous (frequency of experiencing the issue) response options. It will also be important to assess if losing this nuance is worth the practical, logistical, or cost advantages. Specifically, comparing findings from administering the scales with dichotomous and polytomous response options in similar populations will permit informed decisions about which format of responses best capture the information that is most important to

organizations, researchers, and policymakers. It will also be valuable to validate dichotomous response options in diverse contexts, particularly high-income countries and areas with low water insecurity prevalence, to determine their robustness across settings. Whilst the sample used in our study contained data from low-, middle-, and high- income countries, there are only two countries that were formally classified as high-income. Further research is required in high-income settings to understand how use of dichotomous response options in WISE surveys may affect measurement of water insecurity in contexts where it is less prevalent.

Conclusion

Polytomous responses options provide more information, but dichotomous response options hold promise for measuring water insecurity when there is need for a more rapid but still comprehensive survey. For program evaluation, WISE Scales with polytomous responses are likely more suitable because they offer greater nuance in understanding both if an experience occurred as well as its frequency. WISE Scale items with dichotomous response options have the potential to provide a time-saving, valid alternative to polytomous response options for measuring occurrence of water insecurity experiences and estimating prevalence of no-to-marginal, low, moderate, and high water insecurity. Additional data collection using dichotomously phrased responses is needed to fully understand all that might be gained and lost with the dichotomization of WISE response options.

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Data Availability

This study was based on survey data collected by Gallup World Poll (GWP) and ENSANUT 2021. Data from ENSANUT are publicly available on the website of the National Institute of Public Health (Mexico). Nationally aggregated WISE data can be accessed from https://doi.org/10.21985/n2-avk4-9932, additional data can be requested by emailing WISE_scales@northwestern.edu.

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Table 1. *Odds of reporting water quality dissatisfaction in relation to the reported frequency of experiencing each WISE item (weighted and adjusted for country) using nationally representative data from 38 countries (n= 50,768, Gallup World Poll 2020, 2022).**

			95% Confidence Interval (CI)	
Items		Odds Ratio (OR)	Lower CI	Upper CI
Worry	Rarely	2.92	2.67	3.19
(n=51,941)	Sometimes	3.55	3.26	3.86
	Often/Always	8.20	7.40	9.08
Plans	Rarely	2.84	2.59	3.11
(n=51,875)	Sometimes	3.30	3.03	3.58
	Often/Always	6.08	5.39	6.86
Hands	Rarely	2.27	2.02	2.55
(n=52,014)	Sometimes	2.74	2.47	3.04
	Often/Always	4.29	3.65	5.04
Drink	Rarely	2.62	2.36	2.90
(n=52,009)	Sometimes	3.25	2.96	3.58
	Often/Always	5.07	4.39	5.86
Food	Rarely	2.43	2.19	2.70
(n=51,861)	Sometimes	3.12	2.86	3.41
	Often/Always	5.42	4.72	6.21
Interrupt	Rarely	2.35	2.16	2.56
(n=51,752)	Sometimes	3.11	2.86	3.38
	Often/Always	5.93	5.37	6.55
Body	Rarely	2.38	2.15	2.64
(n=52,028)	Sometimes	3.04	2.76	3.36
	Often/Always	4.99	4.28	5.83
Clothes	Rarely	2.56	2.33	2.80
(n=51,969)	Sometimes	3.17	2.90	3.45
	Often/Always	5.99	5.30	6.77
Angry	Rarely	2.78	2.54	3.05
(n=51,940)	Sometimes	3.45	3.18	3.75
	Often/Always	7.12	6.38	7.94
Sleep	Rarely	2.69	2.39	3.03
(n=52,013)	Sometimes	2.88	2.58	3.21
	Often/Always	4.85	4.05	5.79
None	Rarely	2.71	2.45	3.00
(n=51,969)	Sometimes	3.43	3.12	3.76
	Often/Always	6.04	5.25	6.94
Shame	Rarely	2.55	2.30	2.82
(n=51,897)	Sometimes	3.31	3.03	3.62
	Often/Always	5.62	4.91	6.43

**Reference for all models was "Never".*

Table 2. Unweighted linear regression of the 12-item IWISE Scale (using polytomous responses) on simulated IWISE scores (using two strategies for dichotomizing responses, "Any Affirmation" and "Sometimes-to-Always Affirmation") and scores from the 4-item IWISE Scale, averaged across 38 countries (n=50,768*, Gallup World Poll 2020, 2022)

	Any Affirmation			Sometimes-to-Always Affirmation			4-item IWISE Scale		
	Mean	Median	Range	Mean	Median	Range	Mean	Median	Range
RMSE**	2.96	2.82	0.78-4.21	2.73	2.51	1.13-3.35	2.72	2.58	0.96-3.54
Beta coefficient	1.98	1.95	1.39-2.26	2.35	2.35	2.13-2.6	2.68	2.65	2.24-2.84
SE	0.0240	0.0236	0.00643-0.0353	0.0260	0.0254	0.00761-0.0463	0.0298	0.0302	0.00843-0.0371
R-Squared	0.864	0.862	0.747-0.932	0.884	0.894	0.725-0.939	0.882	0.883	0.804-0.954
Correlation	0.929	0.929	0.865-0.966	0.940	0.946	0.852-0.969	0.939	0.940	0.897-0.977

**Per country N Mean=980; Median=1336; Range= 878-12349; **RMSE: Root Mean Squared Error.*

776 **Table 3. Summary of research questions, analyses performed, and results**

Abbreviated research question	Analyses	Results
1. Is the response "rarely" meaningful in the gradation water insecurity experiences?	Estimated the frequency of people responding "rarely" to each of the WISE items. Tested if responses of "rarely" on different items predicted dissatisfaction with water quality using logistic regression.	Rarely experiencing a water related issue is strongly related to higher odds of dissatisfaction with water quality. (Figure 2, Table 1).
2. Do WISE-12 scores calculated with dichotomized responses accurately predict WISE scores calculated from polytomous responses?	2.1 Ran linear regression models, with dichotomous response scores as explanatory variable & polytomous response scores as outcome variable 2.2 Receiver operating characteristic (ROC) curves to explore the how well different scores using dichotomised responses accurately estimate moderate-to-high water insecurity 2.3 Estimated and compared prevalence of water insecurity using WISE scores with polytomous and dichotomous response options. 2.4 Compared how WISE scores from polytomous versus dichotomized responses predicted dissatisfaction with water quality using logistic regression models	WISE-12 scores from dichotomized responses provided a reasonable approximation to scores with polytomous responses and were similarly predictive of water quality dissatisfaction (Table 2, Supplementary Figure S2, Figure 4, Figure 5)
3. Do WISE-4 scores calculated with polytomous responses more accurately predict WISE-12 scores calculated from polytomous responses vs. WISE-12 scores calculated with dichotomous responses?	We repeated 2.1, 2.3, 2.4, using polytomous responses to 4 WISE items	WISE-12 scores from dichotomized responses and WISE-4 scores from polytomous responses provide comparable approximation to the WISE-12 scores with polytomous responses and are comparatively predictive of water quality dissatisfaction (Table 2, Supplementary Table S6C, Figure 5).
4. How well can different cut-offs of WISE scores from dichotomized responses differentiate between different levels of water insecurity estimated using WISE-12 scores with polytomous responses?	Used ROC to find cutoffs that approximate categories of no-to-marginal, low, moderate, or high water insecurity as defined from WISE-12 scores using polytomous responses.	WISE scores from the dichotomized responses can be used to estimate the number of individuals experiencing no-to-marginal, low, moderate, or high water insecurity. Exact cut-offs should be developed and validated using data collected with dichotomous responses rather than using dichotomized data from polytomous responses.

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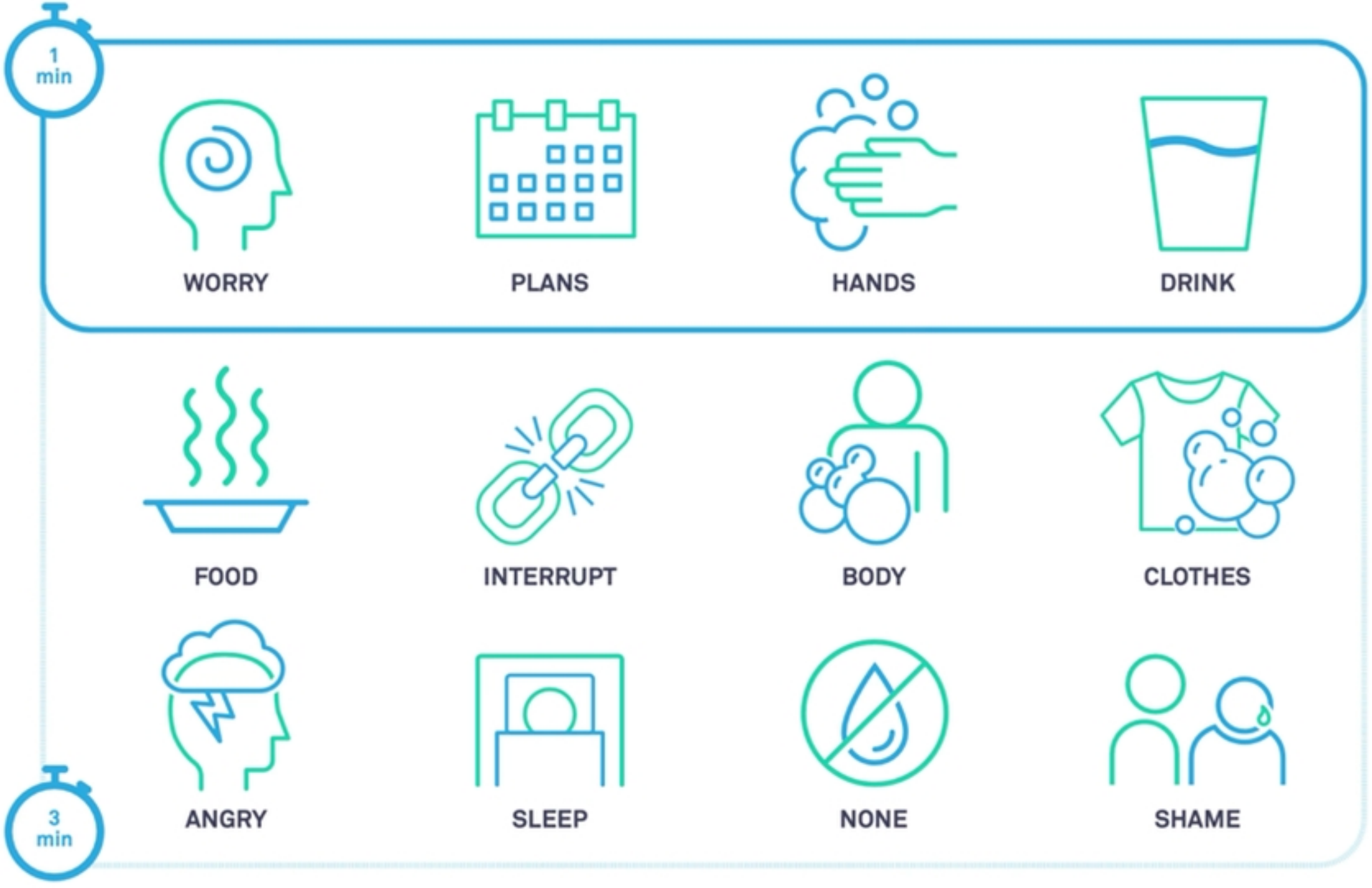
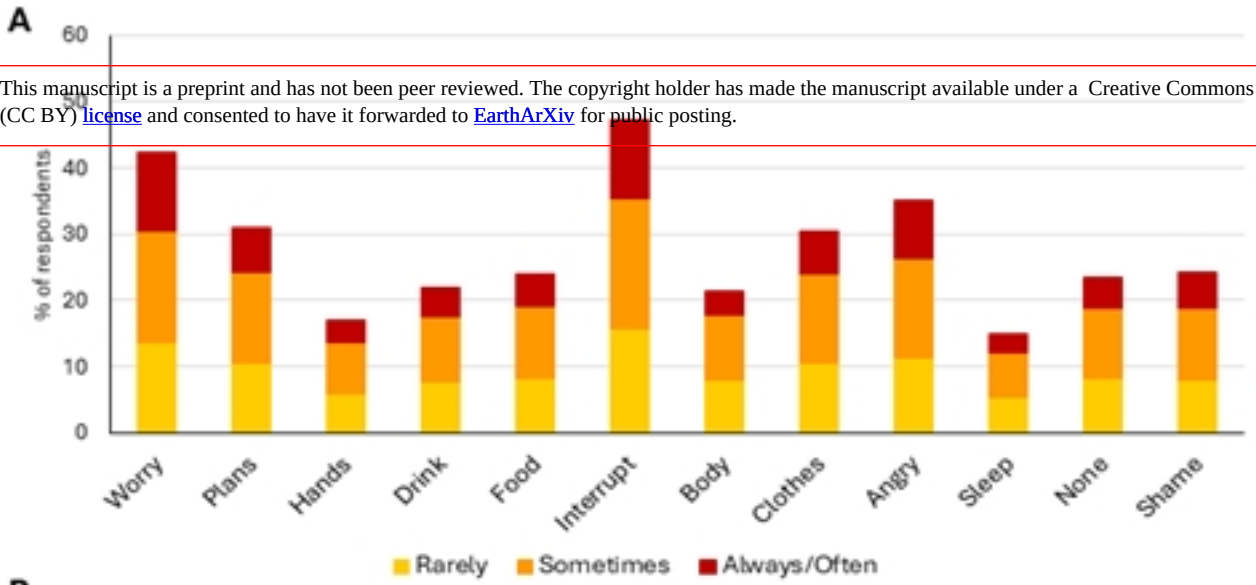
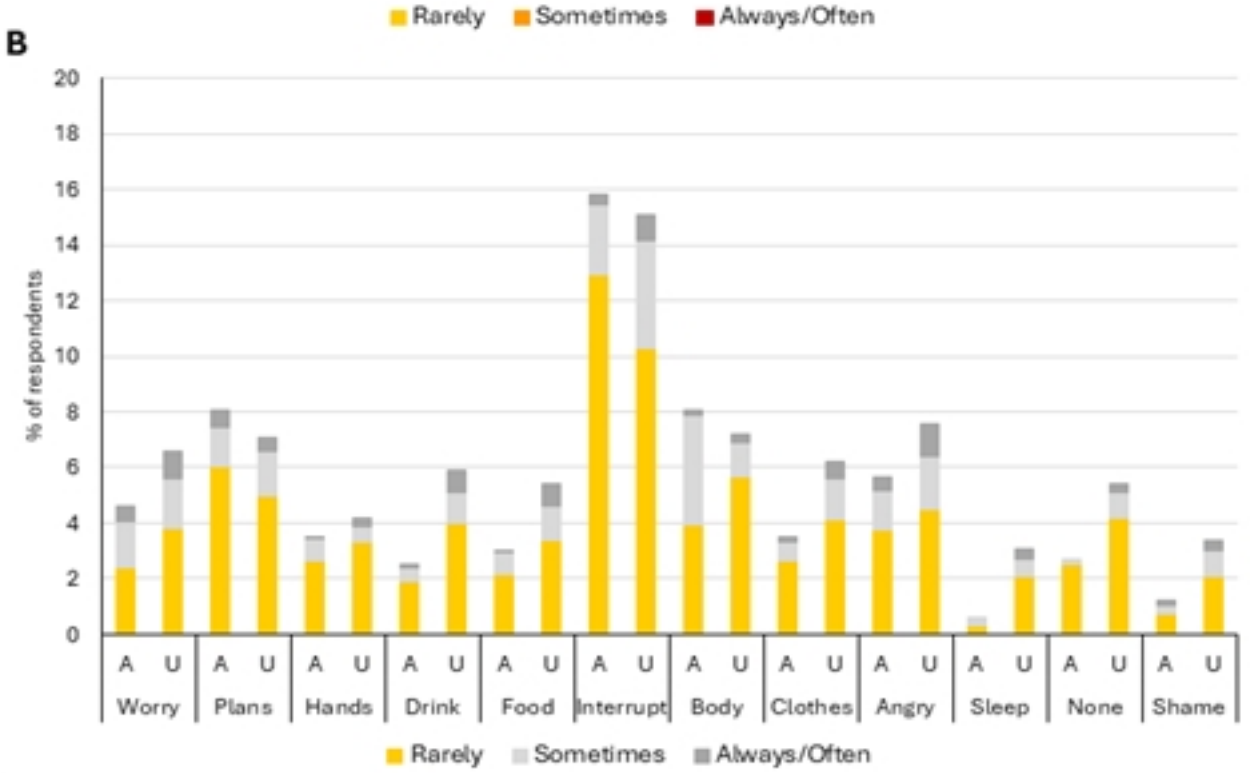

1 min
WORRY
PLANS
HANDS
DRINK
FOOD
INTERRUPT
BODY
CLOTHES
ANGRY
SLEEP
NONE
SHAME
3 min

Figure1





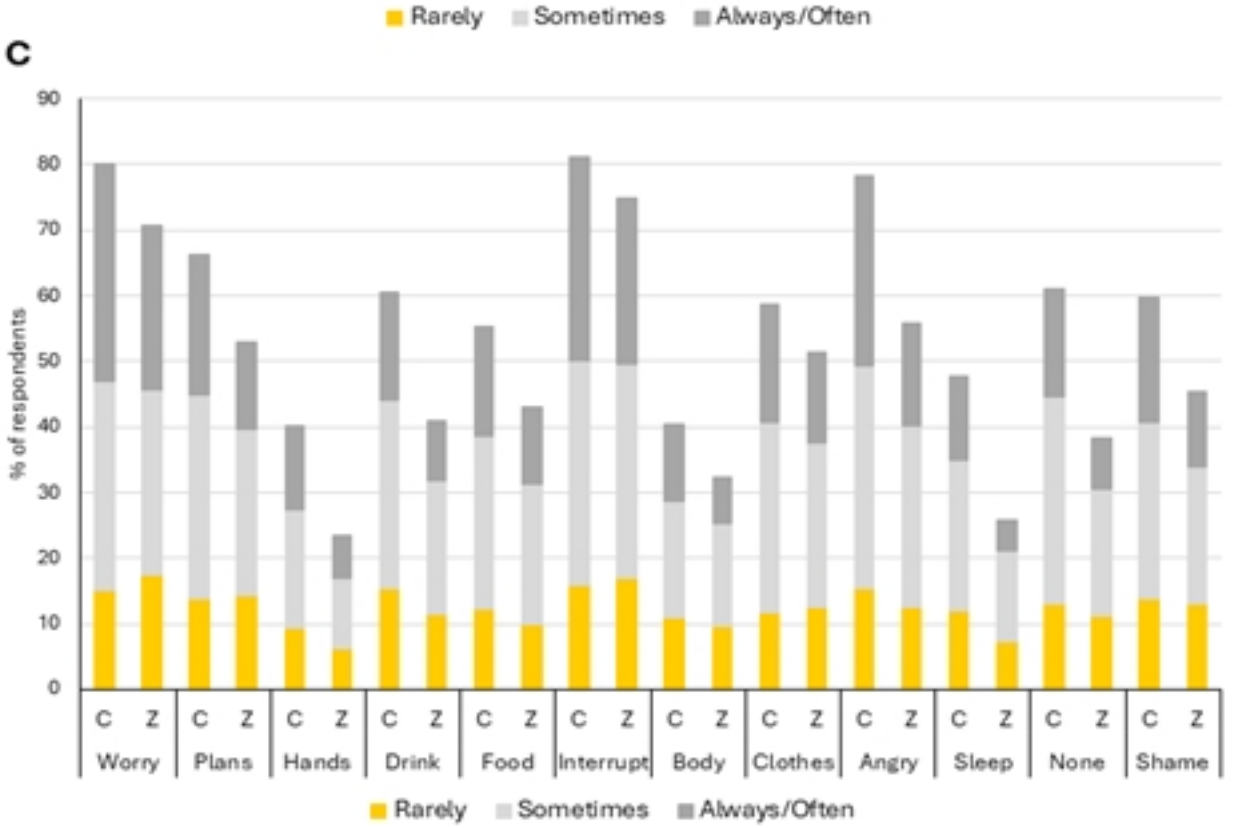


Figure2

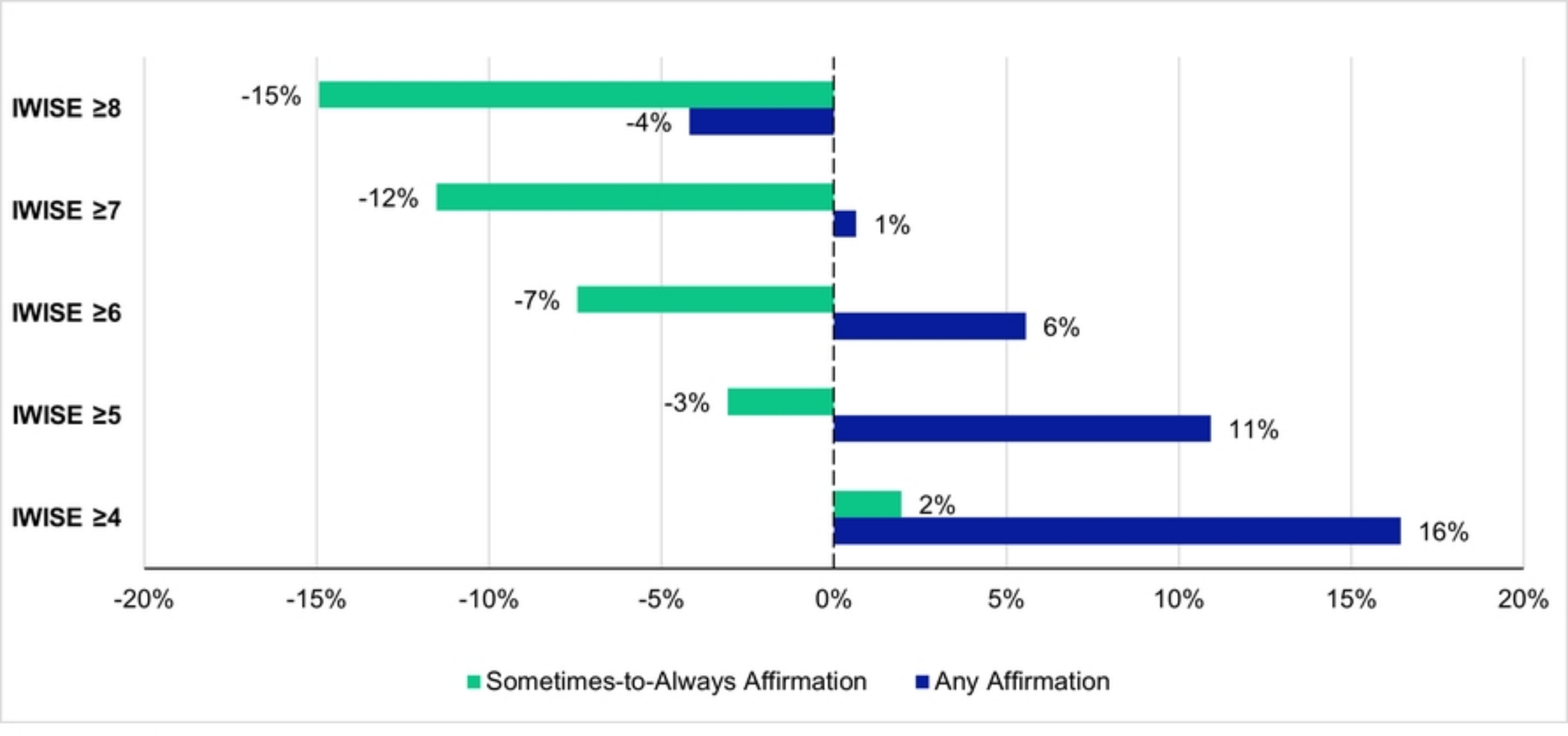

IWISE ≥8
IWISE ≥7
IWISE ≥6
IWISE ≥5
IWISE ≥4
-15%
-4%
-12%
1%
-7%
6%
-3%
11%
2%
16%
-20%
-15%
-10%
-5%
0%
5%
10%
15%
20%
Sometimes-to-Always Affirmation
Any Affirmation

Figure3

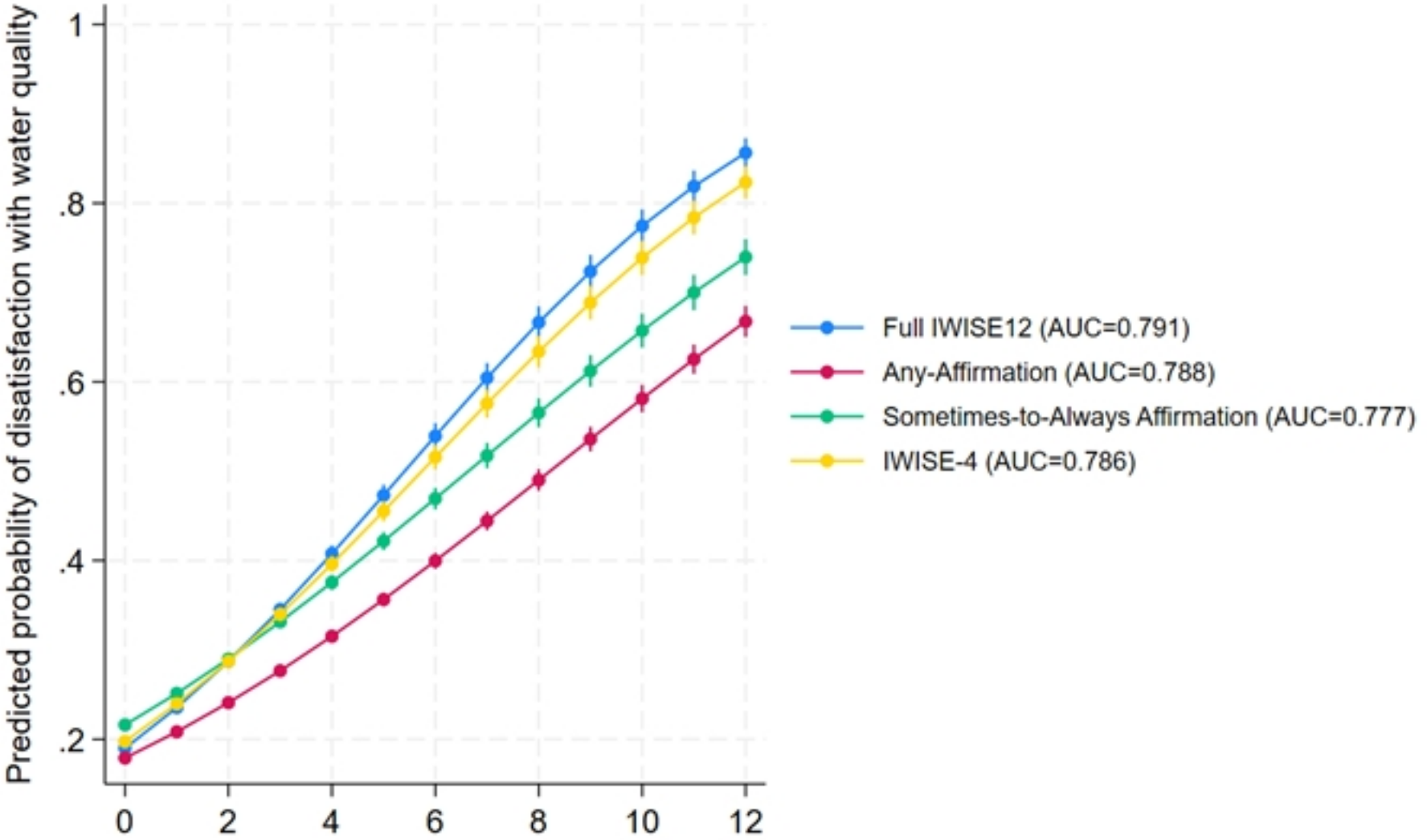

Predicted probability of disatisfaction with water quality
1
.8
.6
.4
.2
0
2
4
6
8
10
12
Full IWISE12 (AUC=0.791)
Any-Affirmation (AUC=0.788)
Sometimes-to-Always Affirmation (AUC=0.777)
IWISE-4 (AUC=0.786)

Figure4

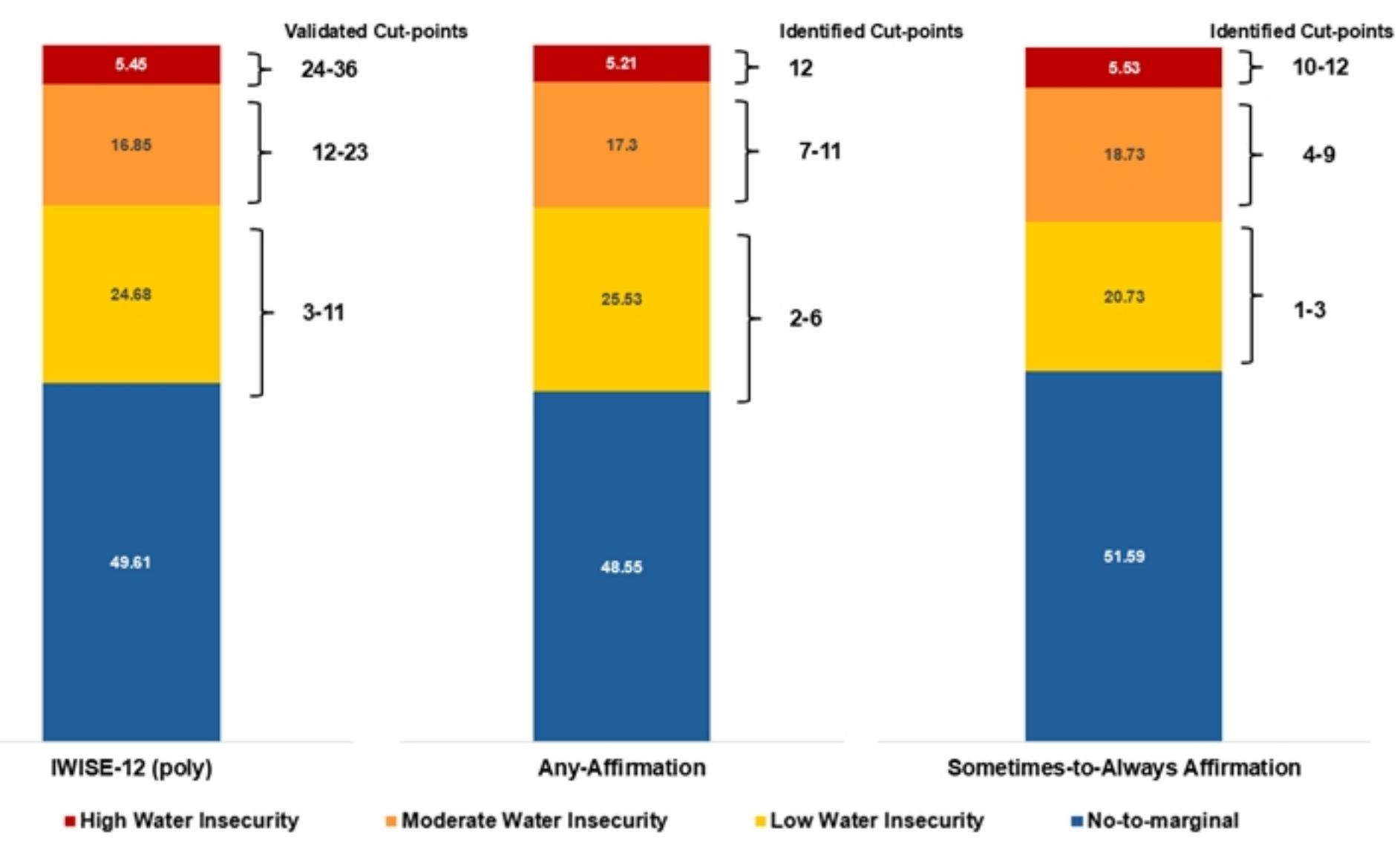

Validated Cut-points
Identified Cut-points
Identified Cut-points
5.45
16.85
24.68
49.61
24-36
12-23
3-11
5.21
17.3
25.53
48.55
12
7-11
2-6
5.53
18.73
20.73
51.59
10-12
4-9
1-3
IWISE-12 (poly)
Any-Affirmation
Sometimes-to-Always Affirmation
High Water Insecurity
Moderate Water Insecurity
Low Water Insecurity
No-to-marginal

Figure5