

1 **Title:** Characterizing the interrelationships of commonly used water measures
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22 **Abstract**

23 There are numerous commonly used measures of household water access that capture various
24 dimensions of the household water experience, but it is unclear if individual variables are
25 complementary, redundant, or uniquely informative. We characterized how measures of
26 household water access are statistically and conceptually interrelated. Using data collected from
27 861 households in Beira, Mozambique we used correlation analyses to characterize relationships
28 between measures of household safe water access, and factor analyses to characterize
29 interrelationships and constructs being measured. In a subset of 75 households, we assessed the
30 parameterization and classification of water quality variables, and how variable definitions
31 impact correlations between variables. Correlation and factor analysis showed that the
32 component variables that make up the WHO/UNICEF Joint Monitoring Programme (JMP)
33 service ladder measured distinct elements related to water access, adequacy, and quality, and that
34 these component variables offer unique information that may not be portrayed when just
35 presenting the JMP water service ladder by itself. User satisfaction was broadly correlated with
36 many variables, even with microbiological water quality, suggesting “satisfaction” captures a
37 breadth of safe household water access. In the factor analysis, the user satisfaction loaded in
38 distinct constructs, indicating potential to reduce these multiple satisfaction variables. How water
39 quality variables were classified (e.g., binary, raw, or log-transformed) strongly contributed to
40 how they correlated with each other. There was little correlation between *Escherichia. coli* (*E.*
41 *coli*) and various pathogens in water. Our research highlights the complexities of relationships
42 between household water access variables, and characterization of these interrelationships inform
43 how to use and interpret measures in research and practice.

44

45 **Keywords**

46 household water access, HWISE, JMP water service ladder, water quality, user satisfaction,
47 factor analysis, correlation analysis

48

49 **1. Introduction**

50

51 Accurately and consistently measuring household safe water access is important for practitioners,

52 policy-makers, and researchers to assess household water service delivery across populations,

53 track intervention effectiveness, and understand the impact of water on health and development

54 outcomes. There are numerous measures of household water access that are commonly used to

55 capture the various dimensions of the household water experience, including water quality,

56 quantity, reliability, acceptability, access, satisfaction, and affordability variables. The water

57 service ladder developed by the WHO/UNICEF Joint Monitoring Programme (JMP) for Water

58 Supply, Sanitation, and Hygiene(1) serves as a dominant measure of the sustainable development

59 goals (SDGs) and water access globally, as it is simple, brief, standardized, scalable and

60 comparable across countries and contexts,(2) but it is not a comprehensive measure.(3,4)

61 Multidimensionality and varied parameterizations of this and other water access measures makes

62 simple, valid characterizations of household safe water access a challenge. Characterizing the

63 interrelationships between measures of household water can help clarify how individual

64 variables are either complementary, redundant, or uniquely informative for evaluation and

65 research applications. The objective of this study was to understand how various measures of

66 household water access are statistically and conceptually interrelated to provide evidence-based

67 guidance on inclusion of measures of water access to complement the JMP water service ladder

68 during evaluation and research.

69
70 The JMP drinking water service ladder has become the global benchmark for tracking household
71 safe water access.(1) One major advantage that has made it the global standard is its simplicity: it
72 is a five-level ordinal measure that condenses several individually measured dimensions of
73 water, including if water is improved, accessible and on the premises, available when needed,
74 and free of fecal and priority chemical contamination. It shares the general limitations of
75 composite measurements (i.e., a single measure created from combining several individual
76 variables), including potential for over-reduction, loss of information, loss of interpretability, or
77 altering relationship strength with outside variables (e.g., outcome variables).(5,6)
78 Notwithstanding the breadth of this measure, it does not capture the full range of household
79 water experiences, limiting its application for a more nuanced understanding of household water
80 access conditions.(3,7) Another limitation is that in many settings throughout the world, data on
81 fecal contamination and priority chemical contamination are not measured or available.(8)
82 Understanding how the JMP drinking water service ladder interrelates with other variables that
83 are meant to capture different characteristics of water can help to identify redundancies, which
84 can inform choices on data collection, analysis, and presentation.

85
86 One criticism of the JMP water service ladder is that it may not capture critical components of
87 household water such as household water insecurity.(7) A measure of water insecurity that is
88 often presented as a complementary measure to the JMP water service ladder is the Household
89 Water Insecurity Scale (HWISE). HWISE is a validated tool that combines 12 items to create a
90 composite focused specifically on water insecurity.(7) There may be substantial overlap between
91 HWISE items and the underlying dimensions of the JMP water service ladder, as HWISE items

92 also explicitly measure elements related to water access, adequacy, reliability, and safety.
93 Characterizing how HWISE, JMP water service ladder, and other measures interrelate may help
94 to understand if measured constructs are distinct, or if the overlap reaches a level that might
95 necessitate analytic considerations for issues like collinearity.(9) The interrelatedness between
96 the JMP water service ladder and HWISE is just one example of many overlapping measures in
97 the literature. Characterizing the interrelationships between measures of safe water access may
98 help to facilitate decisions on variable selection to avoid redundancy and to avoid potential
99 statistical issues.

100
101 Water quality measures are also intrinsically related to the JMP water service ladder, in that
102 being “free of fecal and priority chemical contamination” is a requirement to achieving safely
103 managed drinking water services (e.g., SMDWS; the top rung of the JMP water service
104 ladder).(10,11) Water quality measures are often presented alongside the JMP water service
105 ladder, and while *E. coli* is the standard measure used across water studies, there are many other
106 measures including other indicators of microbial fecal contamination and direct detection of
107 specific pathogens in water samples.(12) Directly measured measures of microbial water quality
108 are not well correlated with the water service technologies.(11,13,14) There is also variability in
109 how water quality is classified (e.g., continuous, ordinal risk categories, presence/absence), and
110 parameterized (e.g., direct concentration or \log_{10} transformed). The combination of the number
111 of water quality measures and all the ways these can be defined may create data visualization and
112 data analysis problems, such as collinearity(9) or multiple testing that leads to type 1 errors.(15)
113 For example, categorizing variables may lead to a loss of information and potentially reduced
114 statistical power(16) and transforming variables may help to facilitate linear relationships but

115 make interpretations of the data more difficult.(17) There is a need for clarity as to which water
116 quality variable definitions are most appropriate.

117
118 Despite widespread use of these various measures of household safe water access, we have
119 limited evidence of how they interrelate, overlap, or are classified and parameterized. For
120 example, the JMP water service ladder has been implemented in numerous countries and
121 contexts throughout the world,(1) but a comprehensive assessment of household safe water
122 access variables is not possible as the number and scope of JMP questions that are asked to
123 households is limited.(10) Work has been done to validate some measures of household safe
124 water access, such as on water insecurity scales,(7,18) but it is unclear how those insecurity
125 scales relate to other related water variables of interest. Similarly, water quality measures such as
126 *E. coli* have been presented in various ways across the literature, including presence versus
127 absence,(1) risk categories,(19,20) use of log transformations,(20,21) or raw counts(21), but
128 papers have not explicitly contrasted and justified these variable definitions. Closing these
129 literature gaps through further research has the potential to help improve harmonization in
130 variable collection during study design, clarify variable classification and parameterizations
131 during analyses, and inform variable interpretations during the dissemination of results.

132
133 We employ data from a longitudinal cohort study in Beira, Mozambique to assess two primary
134 objectives: 1) to characterize interrelationships between many common measures of household
135 water access, using correlation and factor analyses; and 2) assess how classification and
136 parameterization influence these associations.

137

138 **2. Materials and Methods**

139

140 ***2.1 Study setting***

141 We used data collected from the enrollment visit of PAASIM (Pesquisa sobre o Acesso à Água e
142 a Saúde Infantil em Moçambique; In English—Research on Access to Water and Child Health in
143 Mozambique), a matched cohort study in Beira, Mozambique. The PAASIM Study employed a
144 prospective group-matched cohort design to assess the impacts of piped water supply on gut
145 health of infants living in low-income neighborhoods in Beira. The details of the study protocol
146 and design are described elsewhere.(22,23) The enrollment visit was conducted when women
147 were in their second or third trimester of pregnancy.

148

149 ***2.2 Data collection***

150 *Household data collection:* Of prenatal participants enrolled in the study at the pre-birth visit, we
151 collected relevant data from 861 households, and had complete data on all variables of interest
152 from 744 households. Data for the pre-birth visit were collected by enumerators using open data
153 kit (ODK) between February 2021 and September 2022. Collected data included measures
154 related to drinking water, such as aspects of water quality, water access, water availability, water
155 security, water consumption, and participant satisfaction with water.(24) Data were collected
156 using a variety of methods, including structured observation, reports from respondents, and
157 objective measurements. Individual measures are described in detail in the variables subsection.

158

159 *Laboratory and sample collection:* We assessed fecal indicators, pathogens, and chlorine in
160 water samples. Different measures required different collection processes:

161 1) *E. coli* and total coliforms in water. We collected 100-mL of water from both the
162 source (e.g., tap) and stored (e.g., in jerry cans) water at each household and assessed each
163 sample for a number of water quality measures. We quantified total coliforms and *E. coli* using
164 the Colilert-18 reagent and the Quanti-Tray/2000 most probable number (MPN) method (IDEXX
165 Laboratories, Westbrook, ME, USA).(25)

166 2) *Chlorine*. The 100-mL samples collected at each sample were also tested for free and
167 total chlorine levels using a Hach (Loveland, CO) DR300 pocket colorimeter.

168 2) *Pathogens in water*. In a subset of 75 households, we collected larger volume (1-2
169 liters) samples from stored water sources. We used membrane filtration to concentrate the
170 sample and stored the filters in 1 mL of Zymo DNA/RNA Shield (Zymo Research, Irvine, CA) at
171 -20°C until transport to the analysis laboratory at UNC Chapel Hill where they were stored at -
172 80°C until nucleic acid extractions were performed. Filters were eluted and extracted using the
173 Qiagen 96 Virus HT kit (Qiagen, Hilden, Germany), and extracts were analyzed with RT-qPCR
174 using a custom TaqMan Array Card (ThermoFisher Scientific, Waltham, MA) with 29 bacterial,
175 viral, and protozoan enteric pathogen targets. Gene copies per reaction was converted to
176 organisms per 100 mL using the number of the target gene contained in one organism of the
177 pathogen and back calculations accounting for the sample volume, elution volume, extraction
178 input and output volumes, and PCR input.

179

180 **2.3 Variables**

181 We used data on many different variables, including the JMP water service ladder (and
182 component parts), the HWISE water insecurity scale (and component items), a user satisfaction
183 scale (and component items), total coliform and *E. coli* measures in both source and stored water,

184 water pressure, chlorine residual, water pathogens (in a subset of 75 stored samples), and other
185 water measures that characterize various aspects of household safe water access, including water
186 quality, water source characteristics, and water-related experiences.

187

188 Water quality

189 *E. coli* and total coliform indicators: We assessed total coliforms and *E. coli* in water in several
190 different ways:

191 1) *MPN concentrations*. *E. coli* and total coliform concentrations were left in their
192 original units, MPN/100mL.

193 2) *log₁₀ transformed concentrations*. *E. coli* and total coliform concentrations were log₁₀
194 transformed from their original units of MPN/100mL. Because log₁₀ (0) is undefined, we
195 converted values of 0 MPN/100mL to 0.1 to correspond to log₁₀ value / category of -1.

196 3) *Risk categories*. *E. coli* and total coliform concentrations were categorized into five
197 risk categories (<1, 1-9, 10-99, 100-999, 1000-9999 MPN/100mL). As we could use a nominal
198 variable for our correlation analyses, we created an ordinal variable corresponding to log₁₀ MPN
199 values(20) where values of 1, 10, 100, 1000 MPN/100mL correspond to log₁₀ values of -1, 0, 1,
200 2, and 3. These categories can be interpreted easily as MPN/100mL risk categories (<1, 1-9, 10-
201 99, 100-999, 1000-9999).

202 4) *Presence versus absence*. *E. coli* and total coliform concentrations were each
203 separately categorized into a binary variable that measures if there was any contamination (≥ 1
204 MPN/100mL).

205

206 *Pathogens*: Like the indicator data, we assessed the pathogen data in several different ways,
207 including non-transformed concentrations, \log_{10} transformed concentrations, and as a binary
208 presence or absence variable. Samples only showed quantifiable levels of the following
209 pathogens: 1) *Campylobacter jejuni*, 2) enteroaggregative *E. coli* (EAEC) defined by presence of
210 the aaiC gene (hereafter EAEC-aaiC), 3) EAEC defined by the presence of the aatA gene
211 (hereafter EAEC-aatA), 4) typical enteropathogenic *E. coli* (tEPEC), 5) atypical
212 enteropathogenic *E. coli* (aEPEC), 6) enterotoxigenic *E. coli* (ETEC) positive for the LT gene
213 (hereafter ETEC-LT), 7) ETEC positive for the STp gene (hereafter ETEC-ST), 8) *Salmonella*
214 *enterica*, 9) *Cryptosporidium* spp. 10) *Giardia* spp. We compared each subtype/or virulence
215 factor of each pathogen separately, rather than combining by pathogen (e.g., EAEC, EPEC, and
216 ETEC), as different subtypes/virulence factors of a pathogen can occur at different
217 concentrations.

218

219 Water Access

220 *Safely managed drinking water service (SMDWS)*: We produced a binary variable, SMDWS,
221 defined as having an improved water source that is located on premises, available when needed,
222 and free from microbiological contamination, with the referent as all the lower rungs of the
223 ladder.(1) We did not collect data on chemical contamination in households, so that component
224 was not included in these definitions.

225

226 *Basic water service*: We produced a binary variable that corresponds to the proportion of
227 households that have at least basic service (i.e., either safely managed or basic compared to
228 limited, unimproved, or surface water), with the referent as all the lower rungs of the ladder.(1)

229
230 *JMP water access:* Water access was measured using two standard JMP survey questions.(10)
231 The first asks whether water was collected from one’s own dwelling, yard, plot, or elsewhere.
232 The second asks about if the water is collected off site, then the collection time is recorded as the
233 time in minutes it takes household members to get to water and come back.

234
235 *JMP water availability:* The regularity by which water was available from a source was
236 measured using the JMP core question on whether or not one’s household had sufficient
237 quantities of drinking water over the last month.(10)

238
239 *Other (non-JMP) water availability variables:* We also captured water adequacy in several other
240 variables. We compared water availability in hours per day categorized as a binary variable
241 (bottom quartile versus other quartiles). We captured whether households used their main water
242 source for all cooking, cleaning, and bathing activities in the household (versus less than all
243 activities). Participants also reported the number of days in the last week that water was
244 available, and we categorized this into a binary variable where water was either not available at
245 least one day from last week versus water was always available. Participants also reported if the
246 household had a large water storage tank (yes *versus* no).

247
248 *Any fecal contamination:* We also created a binary variable that measures if there was any total
249 coliform or *E. coli* contamination (≥ 1 MPN), measured separately for source and stored water.
250 This variable was used to categorize SMDWS as free from microbiological contamination.

251

252 *JMP water service ladder:* We assessed water service using the JMP water service ladder, an
253 ordinal, five-level measure (i.e., SMDWS =5, basic=4, limited=3, unimproved=2, and surface
254 water=1).(1) To assign households to a category, we followed JMP definitions using responses to
255 a series of standardized survey questions. We determined whether the household's main drinking
256 water source met JMP criteria for being improved. We assessed accessibility, using a question
257 that asked whether the source was located on the household premises, and if the source was not
258 on premises, enumerators recorded the round-trip collection time in minutes. We assessed
259 availability by asking whether the household had sufficient quantities of drinking water available
260 in the past month. We measured microbiological quality by determining the presence or absence
261 of *E. coli* or total coliforms in source water. A household was categorized as having SMDWS
262 (the top rung of the ladder) only if it used an improved source that was located on premises,
263 available when needed, and free from fecal contamination. If a household met all criteria except
264 water quality, it was instead categorized as having basic service. If collection time exceeded 30
265 minutes, the household was downgraded to limited service. Levels of the lower ladder rungs,
266 unimproved and surface water, are uncommon in urban settings.

267
268 *JMP water service ladder excluding quality:* We created a second water service ladder similar to
269 the JMP water service ladder, but excluding the requirement that the water must be free from
270 fecal contamination in order to reach the top rung of the water service ladder. This was done so
271 that we could correlate measures of fecal contamination with the technologies of the service
272 ladder, without having fecal contamination built into the service ladder. Some have used water
273 technologies (e.g., a slab) as proxies for water quality, but these proxies have been criticized as
274 not being strongly related(11,13,14) so we created this variable to assess this relationship.

275

276 Water insecurity

277 *HWISE scale:* In the HWISE scale(7) higher scores indicate greater household water insecurity.

278 The scale was created by asking all respondents 12 questions on how often they experienced
279 different components of water insecurity (adequacy, reliability, accessibility, safety) in the prior
280 4 weeks, and respondents answered either: never (scored as 0), rarely (scored as 1), sometimes
281 (scored as 2), often or always (scored as 3). These 12 items were summed to create the HWISE
282 scale, creating scores ranging between 0 and 36. While HWISE authors recommend focusing on
283 the overarching scale and not the individual items(7) we also evaluated the individual items to
284 understand the interrelationships and redundancies between these items and other variables of
285 interest that potentially measure the same construct.

286

287 *HWISE water insecure:* The continuous HWISE scale was categorized as a binary variable,
288 characterizing households as water insecure (score of 12 or more) *versus* not. This
289 characterization is validated and described elsewhere in the literature.(7)

290

291 *HWISE ordinal categories:* The continuous scale was also classified as an ordinal variable with
292 four categories (0-2=no-to-marginal, 3-11=low, 12-23=moderate, and 24-36=high water
293 insecurity), and the development of these categories is described elsewhere in the literature.(18)

294

295 User satisfaction

296 *Satisfaction scale:* We developed user satisfaction variables that included six items related to
297 how often (always, sometimes, never) the respondent was satisfied with their water 1) service, 2)

298 affordability, 3) availability, 4) pressure, 5) appearance, and 6) smell. These six items were
299 summed to create the satisfaction scale, creating scores ranging between 0 and 12, with higher
300 scores indicating higher satisfaction water.

301

302 Other water measures

303 *Free chlorine:* We measured the presence of free and total chlorine in all source water samples,
304 and used the WHO guideline value for free chlorine residual at the point of delivery of 0.2-2.0
305 mg/L.(19)

306

307 *Water treatment:* The use of any treatment of stored water to make it safer to drink was reported
308 by participants. Treatments included boiling, adding bleach/chlorine, straining through cloth,
309 using a water filter, solar disinfection, settling, and none.

310

311 *Time collecting water:* Participants reported the weekly amount of time in minutes spent
312 collecting water.

313

314 *Water available for handwashing:* Water availability at the handwashing facility during the visit
315 was observed by enumerators and recorded as a binary variable (available versus not).

316

317 *Flow rate:* The flow rate of water at the source was measured in volume per seconds by taking
318 the volume of the container was being used for collection (measured in L), and dividing by the
319 time it took to fill the container.

320

321 *Household water use:* Participants reported how much water (in L) their household used per day.
322 For participants who collected their water, participants showed their collection buckets to the
323 enumerator and estimated how many buckets the household used in a day. We categorized the
324 overall water use into low household consumption (bottom quartile) versus the other three
325 quartiles.

326
327 *Monthly water costs:* Participants reported how much their household spent on water in a typical
328 month (in MZN), and we categorized cost into high water expenses (top quartile) versus the
329 other three quartiles.

330

331 **2.4 Data Analysis**

332 *Descriptive statistics.* We conducted descriptive analyses on each of the measures of household
333 safe water access. Categorical variables were presented as counts and percentages (N, %), and
334 continuous variables were summarized using means and standard deviations (mean, SD). We
335 hypothesized the constructs upon which variables would group, along with the descriptive
336 statistics for each variable. Constructs were developed *a priori* based on theoretical frameworks
337 or domain expertise.

338 *Correlation analyses of measures of household safe water access.* We used correlation analysis
339 to characterize relationships between various water quality measures, and composites that
340 measure household safe water access in the literature. We evaluated correlations between
341 commonly used composites, including the HWISE scale, the JMP water service ladder composite
342 measure, and our own user satisfaction scale, and we assessed how these correlated with

343 microbiological water quality indicators (*E. coli* or total coliform contamination in source and
344 stored water). This aligns with our first study aim, *to characterize interrelationships between*
345 *many common measures of household water access*. We also evaluated correlations between
346 different parameterizations and classifications of the same variable construct (e.g., the entire
347 JMP water service ladder compared to SMDWS). This aligns with our second study aim, *to*
348 *assess how classification and parameterization influence associations*.

349 We developed a correlation heatmap to visualize the correlation coefficients between each of the
350 variables of interest, and the statistical significance levels of these associations. Many primary
351 measures of interest were composed of sub-components that might measure similar constructs,
352 including water adequacy, reliability, and accessibility, so we hypothesized that because of these
353 overlapping sub-components there might be relationships between overarching measures like
354 HWISE and the JMP water service ladder (even if the overarching measures were intended to
355 measure something different).

356 We also assessed the correlations between the component items of these larger composites (e.g.,
357 12 HWISE items, individual JMP questions, individual satisfaction questions, and other
358 measures of household safe water access. This analysis also aligns with our first study aim, *to*
359 *characterize interrelationships between many common measures of household water access*,
360 which has the potential to inform decisions on model specification/variable selection, to identify
361 non-redundant measures, to assess construct validity, and to improve interpretation of results.

362
363 *Factor analyses of measures of household safe water access*. We explored and characterized
364 interrelationships between variables using factor analysis.(26,27) We used a parallel analysis

365 scree plot to determine the number of factors to retain, where factors up to and including the
366 elbow point where the observed eigen values become smaller than the random data eigenvalues
367 would be retained. Factor analysis was performed using the varimax rotation method using the
368 number of factors indicated from the parallel analysis scree plot. We report factor loadings, the
369 proportion of the variance explained, and show the relationship between factor loadings using a
370 heatmap. For our factor analysis, we included the component items of these larger composites
371 (e.g., HWISE, satisfaction, JMP water service ladder), along with other measures of household
372 safe water access. It is not standard to individually use the 12 individual items that make up the
373 HWISE scale, but these items were of interest as these items also measure water adequacy,
374 reliability, and accessibility, and we wanted to characterize if and how these items correlate to
375 other variables of ours that measure similar constructs. The results obtained from this factor
376 analysis also aligns with our first study aim, *to characterize interrelationships between many*
377 *common measures of household water access*, and should be useful to gain insights into the
378 latent constructs that underlie our observed variables. We hypothesized that this analysis would
379 help to identify and target unique constructs shared by multiple variables, or to target individual
380 variables that have unique contributions to safe water access.

381
382 *Classification, parameterization and correlation of water quality variables.* Due to the large
383 number of potential classifications and parameterization of water quality variables, we conducted
384 a separate analysis that assessed the correlation between various water pathogen classifications
385 (concentrations, log₁₀ concentrations, or as a binary variable) and various *E. coli* classifications
386 (concentrations, log₁₀ concentrations, risk categories, or as a binary variable). This aligns with our

387 second study aim, *to assess how classification and parameterization influence associations*. All
388 data and analyses were performed using the R programming language (R version 4.2.3).

389

390 ***2.5 Ethics Statement***

391 Recruitment and informed consent took place at the households prior to enrollment. Subjects
392 provided written consent with a signature or with a thumbprint, if they were unable to read. The
393 study was approved by the Mozambique National Bio-Ethics Committee for Health (Ref:
394 105/CNBS/20), and the Institutional Review Board of Emory University (IRB#: CR001-
395 IRB00098584, Atlanta, GA). We also obtained permissions to carry out the research from local
396 authorities in Beira, including the Beira municipality, and municipal district administrations from
397 study neighborhoods.

398

399 **3. Results**

400

401 ***3.1 Descriptive statistics***

402

403 All participants (100%) had an improved water source, as defined by the JMP, although only
404 57% had that source located on the premises, 96% had a collection time less than 30 minutes,
405 and 81% reported sufficient water over the last month (Table 1). Very few households had
406 drinking water classified in the lower rungs of the JMP water service ladder (0 unimproved; 0
407 surface water). Common JMP categorizations showed 186 households (25%) had SMDWS and
408 723 households (97%) met the threshold of basic drinking water (Table 1). The ordinal HWISE
409 measure showed 180 (24%) of households had either moderate or high water insecurity. The

410 HWISE item that had the highest insecurity score was whether the main water source had been
 411 interrupted or limited. Of the source water samples, 366 (49%) had no fecal contamination with
 412 *E. coli* and/or coliforms, and 467 (63%) had free chlorine at or above WHO recommended
 413 levels. Of the stored water samples, 323 (43%) had detectable *E. coli*, while 170 (23%) of
 414 participants reported a treatment method for their stored water. In a subset of 75 stored water
 415 samples that were assessed for water pathogens, 10 different pathogens were detected from a
 416 panel of 29 bacterial, viral, and protozoan enteric pathogen targets, with *Cryptosporidium* spp.
 417 being the most common pathogen (27%). Participants often reported that they were always
 418 satisfied with availability, pressure, affordability, and service (all had satisfaction scores ≥ 1.5)
 419 with slightly lower satisfaction in water appearance (1.2) and taste and smell (1.3).

420

421 **Table 1. Household safe water access variable definitions and descriptive analyses (N=744).**

Measure	Hypothesized construct	Measured variable	N, % or Mean (SD)
JMP measures	Accessible	located on premises	422, 57%
		collection time less than 30 minutes	716, 96%
	Sufficient Quality	households report having sufficient water over last month	599, 81%
		no <i>E. coli</i> or coliforms detected in source water	366, 49%
	JMP service ladder level	JMP Safely Managed Drinking Water Services (SMDWS)	186, 25%
JMP at least basic		723, 97%	
JMP improved water source		744, 100%	
HWISE scale Ordinal insecurity: no =386, 52% low=178, 24% moderate=150, 20% high =30, 4%	Accessible	HW10.* gone to sleep thirsty because there wasn't any water to drink	0.31 (0.64)
		HW11. no useable or drinkable water whatsoever in your household	0.45 (0.76)
		HW1. worry not have enough water for all of your household needs	0.63 (0.79)
	Sufficient	HW3. problems with water meant that clothes could not be washed	0.68 (0.90)
		HW4. change schedules or plans due to problems with your water situation	0.46 (0.70)
		HW8. there not been as much water to drink as you would like	0.48 (0.78)
	Reliable	HW2. main water source been interrupted or limited	0.72 (0.82)
		HW5. change what was being eaten because problems with water	0.35 (0.67)
	Safety/well-being/health	HW6. go without washing hands because of problems with water	0.35 (0.64)
		HW7. go without washing their body because of problems with water	0.35 (0.63)
		HW9. feel angry about your water situation	0.61 (0.86)
		HW12. problems with water caused to feel ashamed /excluded/stigmatized	0.45 (0.74)
Satisfaction	Accessible	satisfied with water availability (always/sometimes/never)**	1.6 (0.59)
	Pressure	satisfied with water pressure (always/sometimes/never)	1.6 (0.56)
	Service/cost	satisfied with water affordability (always/sometimes/never)	1.6 (0.62)
		satisfied with water service (always/sometimes/never)	1.5 (0.61)
		satisfied with water color & appearance (always/sometimes/never)	1.2 (0.53)

	Physical characteristics	satisfied with water taste and smell (always/sometimes/never)	1.3 (0.59)	
	Accessible	minutes per week spent by mother collecting water from main water source	54 (94)	
Other water measures	Sufficient	water available at handwashing facility	387, 52%	
		use main drinking water source for all activities	661, 89%	
	Pressure	low water availability (hours per day)	207, 22%	
		water not available at least one day from last week	167, 22%	
	Usage	household has large water storage tank	45, 6.0%	
		pipelined water low flow rate (L / second)	0.13 (0.34)	
	Service / cost	low household consumption of water	297, 40%	
		high water expenses	200, 27%	
	Quality / safety	Stored water pathogens*** per 100 mL of drinking water:	any treatment of stored water to make safer to drink	170, 23%
			free chlorine residual at the point of delivery ≥ 0.2 & < 5 mg/L	467, 63%
any fecal contamination (<i>E. coli</i> or total coliforms) in source water			378, 51%	
any <i>E. coli</i> contamination in source water			89, 12%	
any total coliforms contamination in source water			378, 51%	
any fecal contamination (<i>E. coli</i> or total coliforms) in stored water			654, 88%	
any <i>E. coli</i> contamination in stored water			323, 43%	
any total coliforms contamination in stored water			654, 88%	
			N=75	
			1) <i>Campylobacter jejuni</i>	1, 1.3%
	2) <i>Cryptosporidium</i> spp.	20, 27%		
	3) <i>Giardia</i> spp.	7, 9.3%		
	4) Enteroaggregative <i>E. coli</i> (EAEC)-aaiC,	4, 5.3%		
	5) EAEC-aatA	3, 4.0%		
	6) Typical enteropathogenic <i>E. coli</i> (tEPEC)	1, 1.3%		
	7) Atypical EPEC (aEPEC)	2, 2.7%		
	8) Enterotoxigenic <i>E. coli</i> (ETEC)-LT	2, 2.7%		
	9) ETEC-ST	1, 1.3%		
	10) <i>Salmonella enterica</i>	2, 2.7%		

422 *HWISE items scored as never=0, rarely=1, sometimes=2, often or always=3. **Satisfaction
 423 items scored as always=2, sometimes=1, never=0. ***Assessed using TaqMan Array Card for 29
 424 bacterial, viral, and protozoan enteric pathogen targets; only the 10 shown pathogens detected in
 425 at least one stored water sample are shown.

426
427

428 429 **3.2 Correlation analyses of measures of household safe water access.**

430

431 Relating to our first study aim, there was correlation between water satisfaction and each of the
 432 other variables in the analysis, including microbiological water quality, household water
 433 insecurity, the technologies of water that households use, and the HWISE scale (Fig 1). The
 434 HWISE scale was strongly correlated with the ordinal (Pearson correlation coefficient (r) = 0.95;

435 $p < 0.001$) and binary ($r = 0.87$; $p < 0.001$) HWISE measures, but was not meaningfully
436 correlated with most other variables in this analysis. There was a moderate correlation between
437 JMP water service levels and any fecal contamination in source water ($r = -0.59$; $p < 0.001$), but
438 that was expected as fecal contamination at the source is intrinsically part of the JMP water
439 service level definition (i.e., no fecal contamination is required in order to be categorized as
440 “safely managed water”). There was no correlation between any of the water quality measures
441 and the reconstructed service level variable that excludes fecal contamination.

442
443 **Fig 1. Correlation between water quality, water scales and composite measures.**
444 * $p < 0.05 - 0.01$. ** $p < 0.01 - 0.001$. *** $p < 0.001$.
445

446 Relating to our second aim, the JMP water service ladder was highly correlated with SMDWS
447 (versus basic or less; $r = 0.94$; $p < 0.001$), and the JMP water service ladder was moderately
448 correlated with having at least basic DW (versus limited; $r = 0.43$; $p < 0.001$). While most of the
449 six water quality measures were all statistically correlated with each other (i.e., $p < 0.05$), the
450 associations comparing microbiological measures between source and stored water were
451 generally weak, and the associations between microbiological measures within a single water
452 type were generally moderate to strong.

453
454 The numerous correlations between all the individual measures of household safe water access,
455 including the component variables that are used to construct the JMP water service ladder, items
456 that make up HWISE, items that make up water satisfaction scale, and various other measures of
457 household safe water access are shown in the appendix (S2 Fig). Variables designed to measure a
458 specific construct were strongly correlated with each other, for example, all 12 of the HWISE
459 items assessing water insecurity were correlated with each other, all six satisfaction items were

460 correlated with each other, and all water quality measures were correlated with each other. The
461 satisfaction items were also strongly correlated with many of the other variables (e.g.,
462 satisfaction with availability was correlated with 29 other variables, including several water
463 quality variables). Some JMP variables had small correlations, including that having water on the
464 premises was correlated with having sufficient water ($r = 0.12$; $p < 0.01$) and with having less than
465 30 minutes of collection time ($r = 0.1$; $p < 0.01$). Flow rate was correlated with no other variables.

466
467 ***3.3 Factor analyses of measures of household safe water access.***

468 A heat plot resulting from the factor analysis showing the interrelationships between all the
469 variables together is shown in Fig 2 (only factor loadings > 0.3 shown). All the individual
470 HWISE items grouped together to form the first factor, which explained 22.2% of the variance
471 (see S1 Table) and had factor loadings from 0.67 to 0.88. This indicates that water insecurity is a
472 distinct construct composed of only the 12 HWISE items. Four user satisfaction variables
473 relating to water service and availability loaded heavily on the second factor. The other two
474 satisfaction variables relating to physical water characteristics (appearance and taste) loaded onto
475 the last factor. The third factor was primarily having enough water/or water availability offsite,
476 whereas the fourth factor was related to water access at the household. Variables about having
477 adequate water loaded onto the fifth factor. Several variables had high uniqueness, including
478 fecal contamination in the source (uniqueness=0.953), fecal contamination in stored water
479 (uniqueness=0.959), low flow rate (uniqueness=0.994), drinking water used for all activities
480 (uniqueness=0.909), having a water storage tank (uniqueness=0.948), water usage
481 (uniqueness=0.926), water treatment (uniqueness=0.972), and meeting WHO chlorine
482 recommendations (uniqueness=0.927; S1 Table). Throughout this analysis, we assessed six
483 factors, because our parallel analysis scree plot determined that six factors should be retained

484 (see S1 Fig).

485

486 **Fig 2. Heatmap showing factor loadings >0.3.**

487

488 **3.4 Classification, parameterization and correlation of water quality variables.**

489

490 In Table 2, we show the relationship of the *E. coli* indicator variable classified in different ways

491 and the water pathogen variables classified in different ways in 75 stored water samples.

492 Twenty-three of these samples tested positive for at least one pathogen, but the samples that

493 tested positive for a pathogen were often different from the 33 samples that tested positive for *E.*

494 *coli*. There was no correlation between any pathogen presence categorized as a binary variable

495 and each of the *E. coli* indicator classifications (all correlations were < 0.1; all p-values were

496 >0.05; Table 2).

497

498 **Table 2. Correlation coefficients comparing various water pathogen classifications (most**
 499 **probable number (MPN) concentrations, log₁₀ concentrations, or as a binary variable) and**
 500 **various *E. coli* classifications (concentrations, log₁₀ concentrations, risk categories, or as a**
 501 **binary variable) from a subset of 75 stored water samples.**

	<i>E. coli</i> MPN/100mL concentrations	<i>E. coli</i> log ₁₀ concentrations	<i>E. coli</i> risk categories	<i>E. coli</i> presence vs. absence
Any pathogen presence (23/75 positive)	0.076, p=0.518	0.04, p=0.736	0.043, p=0.712	0.051, p=0.662
Pathogen Concentrations (non-transformed)				
<i>Campylobacter jejuni</i>	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
<i>Cryptosporidium</i> spp.	-0.031, p=0.792	-0.093, p=0.427	-0.087, p=0.459	-0.10, p=0.376
<i>Giardia</i> spp.	-0.052, p=0.658	-0.12, p=0.312	-0.11, p=0.332	-0.12, p=0.305
EAEC- <i>aaiC</i>	0.84, p<0.001	0.30, p=0.009	0.33, p=0.004	0.14, p=0.243
EAEC- <i>aatA</i>	0.069, p=0.555	0.17, p=0.147	0.14, p=0.225	0.13, p=0.259
tEPEC	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
aEPEC	-0.030, p=0.796	-0.093, p=0.428	-0.087, p=0.457	-0.10, p=0.379
ETEC-LT	-0.039, p=0.737	-0.067, p=0.568	-0.074, p=0.526	-0.045, p=0.704
ETEC-ST	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
<i>Salmonella enterica</i>	-0.026, p=0.824	0.12, p=0.289	0.12, p=0.305	0.17, p=0.154

Pathogen concentrations (log₁₀ transformed)				
<i>Campylobacter jejuni</i>	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
<i>Cryptosporidium</i> spp.	-0.10, p=0.378	-0.054, p=0.646	-0.048, p=0.681	-0.043, p=0.716
<i>Giardia</i> spp.	-0.075, p=0.525	-0.10, p=0.375	-0.10, p=0.38	-0.082, p=0.486
EAEC-aaIC	0.51, p<0.001	0.18, p=0.119	0.19, p=0.098	0.060, p=0.607
EAEC-aatA	0.44, p<0.001	0.21, p=0.073	0.21, p=0.071	0.10, p=0.387
tEPEC	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
aEPEC	-0.025, p=0.832	-0.016, p=0.893	0.010, p=0.93	-0.042, p=0.722
EPEC-LT	-0.042, p=0.719	-0.037, p=0.751	-0.055, p=0.641	0.010, p=0.933
EPEC-ST	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
<i>Salmonella enterica</i>	-0.033, p=0.781	0.10, p=0.392	0.11, p=0.37	0.19, p=0.111
Pathogen presence (binary)				
<i>Campylobacter jejuni</i>	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
<i>Cryptosporidium</i> spp.	-0.13, p=0.254	-0.098, p=0.401	-0.10, p=0.382	-0.049, p=0.679
<i>Giardia</i> spp.	-0.081, p=0.489	-0.12, p=0.303	-0.12, p=0.314	-0.10, p=0.395
EAEC-aaIC	0.40, p<0.001	0.13, p=0.259	0.14, p=0.231	0.029, p=0.807
EAEC-aatA	0.48, p<0.001	0.21, p=0.076	0.21, p=0.069	0.093, p=0.426
tEPEC	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
aEPEC	-0.016, p=0.89	0.057, p=0.629	0.098, p=0.405	0.020, p=0.865
EPEC-LT	-0.042, p=0.719	-0.031, p=0.791	-0.050, p=0.669	0.020, p=0.865
EPEC-ST	-0.030, p=0.795	-0.093, p=0.427	-0.087, p=0.457	-0.10, p=0.379
<i>Salmonella enterica</i>	-0.034, p=0.773	0.090, p=0.442	0.098, p=0.405	0.19, p=0.109

502 Values are correlation coefficients and p-value. **Bold is p-value < 0.05.** *E. coli* concentrations
503 measured by culture and all the pathogen data measured by qPCR. Enteroaggregative *E. coli*
504 =EAEC-aaIC, EAEC defined by the presence of the aatA gene=EAEC-aatA, typical
505 enteropathogenic *E. coli*= tEPEC, atypical enteropathogenic *E. coli*=aEPEC, enterotoxigenic *E.*
506 *coli* (EPEC) positive for the LT gene= EPEC-LT, EPEC positive for the STp gene=EPEC-ST.
507

508 When assessing the relationship between the *E. coli* indicator and individual pathogens, there
509 was a statistically significant correlation between indicator *E. coli* and both EAEC-aatA and
510 EAEC-aaIC, but only when the variables were not log₁₀ transformed (Table 2); this is influenced
511 by outlying relationship in a small number of samples (e.g., S3 Fig). Log transformation and
512 categorization of the *E. coli* and pathogen variables generally weakened the correlation between
513 variables, as no strong correlations persisted between the *E. coli* indicator measures and any of
514 the pathogens under study once the data were log₁₀ transformed or categorized. Scatterplots
515 depicting the relationship between *Cryptosporidium* and indicator *E. coli* (parameterized 4
516 different ways) depict that by not transforming we have extreme outliers (S4 Fig a), that log

517 transformation mitigates the impact of these outliers (S4 Fig b), and that categorization—
518 especially binary categorization—leads to loss of information (S4 Fig c and d).

519
520 **4. Discussion**

521 Our research highlights the complexities in the relationships between measures of household safe
522 water access, and our characterization of these interrelationships has important implications
523 related to decisions on model construction and variable selection. We found that components that
524 make up the JMP water service ladder were measuring distinct elements related to water access,
525 adequacy, and quality, and as such, these component variables may offer unique information that
526 might be lost by only presenting the overarching composite. User satisfaction appeared to be
527 broadly correlated with many other variables, even with microbiological water quality variables,
528 suggesting the utility of “satisfaction” as a useful proxy for capturing various constructs of
529 access. We also observed grouping of certain variables, such as individual user satisfaction
530 components into distinct constructs, indicating potential to reduce these multiple satisfaction
531 variables using composites/scales. The way that water quality variables were classified (e.g.,
532 binary vs. raw vs. log-transformed) strongly contributed to how they correlated with each other,
533 indicating a need to be thoughtful in how variables are defined. Our microbiological indicators of
534 water quality had high factor analytic uniqueness compared to other variables, indicating these
535 indicators are not captured by other variables. However, we observed very little correlation
536 between *E. coli* indicator organisms and specific pathogens in water.

537
538 We recommend presenting data on the subcomponents of the JMP water service ladder to avoid
539 loss of information and increase transparency. While the JMP water service ladder is important
540 as a concise global indicator, the individual variables that make up the JMP water service ladder

541 were all found to measure distinct constructs and are important in their own right. In the urban
542 context of the PAASIM study, where most people had at least basic water service, the JMP water
543 service ladder was not particularly informative on the differences in water across households, but
544 we did observe heterogeneity across many other JMP variables characterizing household safe
545 water access in this urban context. These findings suggest that while the JMP ladder is effective
546 in rural contexts for tracking transitions to improved services, broader measures of household
547 safe water access will be required to characterize water access in urban low-income settings.

548
549 User satisfaction of water is not regularly assessed in many water studies, but our research
550 suggests that water satisfaction may be a useful catch-all measure. User satisfaction appeared to
551 be both differentiated as a construct, and also broadly correlated with many other variables of
552 relevance. Notably, user-reported satisfaction was more strongly related to microbiological water
553 quality than many of the directly observed household water variables. Water quality measures
554 (such as fecal contamination and priority chemical contamination) are not always measured or
555 available, (8) so satisfaction in quality might be a possible proxy in such situations. Our research
556 highlights that users' perceptions might capture elements of water that are broad in scope and
557 sometimes difficult and expensive to measure or collect. Taking into account user satisfaction
558 also has the advantage of placing increased emphasis on the experience of people living in the
559 environments under study, de-emphasizing the importance of outside expertise or technical
560 measures in studies of water access. Our satisfaction variables consisted of six questions, which
561 if presented separately could clutter analyses, but our factor analyses indicated that these
562 questions might be compiled into a broader satisfaction scale, or possibly two scales (e.g., one
563 assessing satisfaction in the water service and one assessing satisfaction in water's physical

564 characteristics). Further research on user satisfaction measures is needed to develop and validate
565 these findings.

566
567 The way in which water quality and water pathogen variables are classified affects how they are
568 interrelated and interpreted. Due to skewed microbial data distributions, it is common to present
569 the variables with some sort of transformation or categorization. A binary categorization
570 (presence versus absence) of a fecal indicator is a common approach, driven by water safety
571 standards of “safe water” being defined as $<1 E. coli/100mL$.(19) Categorization addresses
572 outliers, but our research implies that binary categorizations of variables may lead to lost
573 information, underestimates of comparisons between groups, and non-linearity in the relation
574 between the variable and outcome.(28) Log-transformations of *E. coli*, pathogens and/or fecal
575 indicators are commonly used in the water literature,(29) but log transformations are sometimes
576 criticized for not being intuitive to interpret for broad audiences, and not being able to handle
577 zero value, as $\log(0)$ is undefined. Researchers may add a constant like 0.1, or halfway between 0
578 and the limit of detection, to each observation before the data are log transformed,(30) but these
579 data manipulations have limitations, as constant size increases, p-values have been shown to
580 decrease, potentially leading to type 1 errors.(31) The geometric mean excludes or adjusts
581 zeroes, which can bias estimates upward, whereas an arithmetic mean may better represents *E.*
582 *coli* risk because it includes zero counts.(32) Risk categories have been used and can share some
583 similarities to the \log_{10} transformation approach (i.e., each increasing risk category is 10x higher
584 than the preceding category).(20) Using risk categories may improve interpretability compared to
585 the log-concentration approach, as zero values are more easily and accurately interpreted as non-
586 detects when they are categorized. Having several categories in an ordinal variable will also

587 preserve more information compared to binary categorizations. However, it is unclear how these
588 deemed “risk” categories are truly tied to health related outcomes at these specific cutoffs,
589 although work is being done on this topic.(33)

590
591 While there is biological plausibility that certain water technologies might be good proxies for
592 water quality, and also plausibility that certain fecal indicators might be good proxies for
593 pathogens in water, we generally found neither. Most of our measures of household safe water
594 access were not correlated with fecal contamination indicators. Our research aligns with that
595 from other studies that have questioned how strongly water source characteristics relate to water
596 quality,(34,35) as higher quality/improved sources have been found to be contaminated with
597 fecal bacteria, and lower quality/unimproved sources have been found to be
598 uncontaminated.(11,13,14,36) Our research also aligns with that from other studies that have not
599 found strong correlations of fecal indicators with pathogens in water.(37,38)

600
601 Our findings support recommendations made by the HWISE authors to not focus on the
602 individual items that make up the HWISE scale.(7) The HWISE scale is distinctly measuring
603 insecurity with little overlap with other variables we assessed. We had initially hypothesized the
604 opposite, that there would be significant overlap between the JMP and HWISE tools, as both
605 have items related to water adequacy, reliability, and accessibility. However, our analyses
606 showed that the 12 HWISE items all grouped on a distinct construct specific to insecurity and
607 were not highly related to the JMP variables. This is relevant, as it might allow for the HWISE
608 scale and JMP variables to co-exist in models without collinearity, and it relays confidence that
609 these are complementary measures that assess different constructs. This finding will help to

610 harmonize the inclusion of HWISE and the JMP variables in research and practice moving
611 forward.

612
613 Our study had several important strengths and limitations. Our study is nested within a large
614 matched cohort study of an urban water supply improvements, and we have rigorously collected
615 data from 861 households with dozens of water measures. On the other hand, while we
616 painstakingly measured and included many water measures that are commonly used in the
617 literature, there are still some variables that were not included in our analyses, such as chemical
618 water quality. We also did not include some of the physical qualities of water (e.g., taste, color,
619 turbidity, odor, hardness, clarity, etc.). Our focus here, because of its theoretical connection with
620 infectious diseases, was the microbiological water quality, using *E. coli* and fecal indicator
621 bacteria, but these are only proxies of what we would wish to measure, which is pathogens in
622 water, and which we were only able to measure in a subset of 75 samples; the pathogen analyses
623 may have been underpowered to detect associations. Another limitation is that our study may not
624 be generalizable to all low- and middle-income country contexts, particularly as the study took
625 place in an urban context.(39) It would be interesting to do a similar analysis in a study carried
626 out in a rural setting.

627

628 **5. Conclusions**

629 This research examined how various measures of household water access are statistically and
630 conceptually interrelated, by characterizing the interrelationships between measures of household
631 water access. Our findings support that there are many variables, including HWISE and those
632 that make up the components of the JMP water service ladder, that provide unique information

633 that can be supplementary to the JMP water service ladder. Our findings suggest that user's
634 perceptions of their water might capture elements of water that are broad in scope and sometimes
635 difficult and expensive to measure or collect, and that this was one of very few measures that
636 correlated with objectively measured water quality. We observed grouping of certain variables,
637 such as individual user satisfaction components into distinct constructs, indicating potential to
638 reduce these multiple satisfaction variables using a single composite or scale. We also found that
639 the way that water quality was classified (e.g., binary vs. raw vs. log-transformed) strongly
640 contributed to how statistical correlations might be interpreted, and we suggest caution and
641 thought to appropriately define these variables. We observed very little correlation between our
642 *E. coli* indicator and various pathogens in water; a finding which has been shown in other
643 studies. Our findings have the potential to advance the literature by helping to improve
644 harmonization in variable collection during study design, clarify variable classification and
645 parameterizations during analyses, and inform variable interpretations during the dissemination
646 of results.

647

648 ***Funding***

649 This work was supported by National Institute of Allergy and Infectious Diseases (NIAID) Grant
650 #R01AI130163 (KL, MF, JG), National Institute of Environmental Health Sciences (NIEHS)
651 Grant #5T32ES12870 and a contract from Autoridade Reguladora de Água, Instituto Público
652 (AURA, IP), Mozambique. The content is solely the responsibility of the authors and does not
653 necessarily represent the official views of the National Institutes of Health. The funders had no
654 role in study design, data collection and analysis, decision to publish or preparation of the
655 manuscript.

656

657 ***Competing interests***

658 The authors have declared that no competing interests exist.

659

660 ***Data Availability Statement***

661 Deidentified data and analysis code can be accessed on our project OSF (Open Science
662 Framework) site upon publication at this link: <https://osf.io/cb7f9>.

663

664 ***Acknowledgments***

665 The authors would like to thank our study participants, who generously gave their time to
666 participate in our survey. We thank the WE Consult field team (Genifa Banze, Gizela Brito,
667 Isabel Chiquel, Marcelo Fernandes, Ligia Jorge, Gerson de Melo, Mario Mungoi, and Ricardina
668 Timoteo) who captured these data.

669

670

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Supporting Information

S1 Fig. Parallel Analysis Scree Plot to determine the number of factors to retain. (DOCX)

S2 Fig. Correlation between all individual household measures of safe water. * $p < 0.05$ – 0.01.
** $p < 0.01$ – 0.001. *** $p < 0.001$. (PNG File)

791 **S3 Fig.** Correlation between EAEC-aaIC and *E. coli* using different variable classifications and
792 parameterizations. Blue shading indicates high density of datapoints are clustered together at the
793 same coordinate. (DOCX)

794
795 **S4 Fig.** Correlation between *Cryptosporidium* spp. and *E. coli* using different variable
796 classifications and parameterizations. Blue shading indicates high density of datapoints are
797 clustered together at the same coordinate. (DOCX)

798
799 **S1 Table.** Variables used to characterize household safe water access in the PAASIM study,
800 factor loadings, and uniqueness scores. (DOCX)

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Figure 1

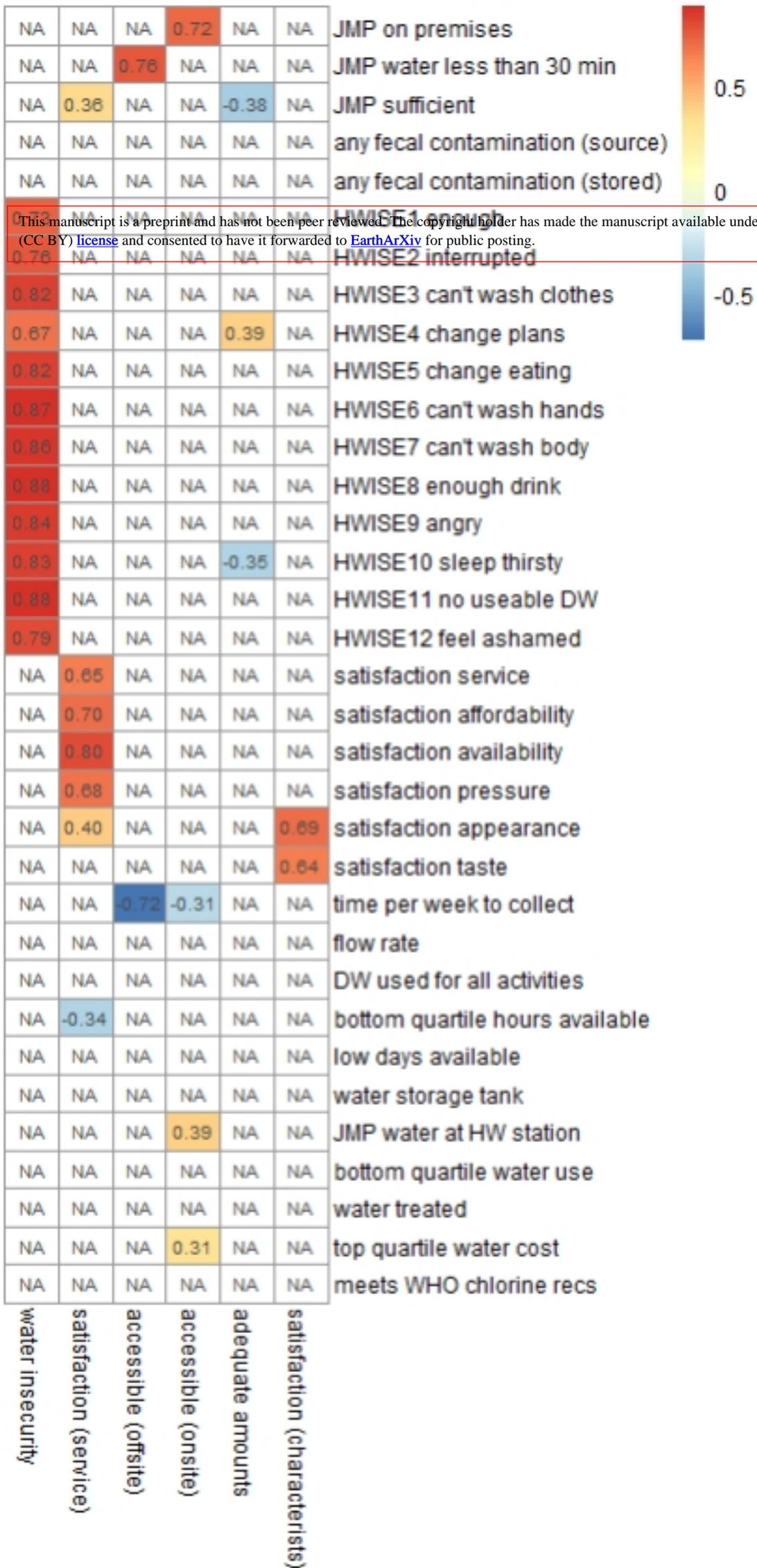


Figure 2