

# Widespread global concern over harm from drinking water

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# Abstract

Poor drinking water quality is a global crisis that affects billions of individuals. Understanding who is most impacted is necessary to develop programs that ensure sustainable, reliable, and resilient access to safe water. But current water indicators do not capture people's experienced and anticipated harm from drinking water, which means we have had limited understanding of how individuals conceptualize, navigate, and are affected by their water environment. Here, we analyzed data from nationally representative surveys undertaken in 142 countries in which people reported their recent experiences and future expectations of harm from drinking water. Prevalence of reported harm from drinking water in the prior two years was 14.5% (range: 0.8%–54.3%). More than half of the world's population (54.4%) anticipated that they would experience serious harm from their drinking water in the next two years. Greater public sector corruption was associated with greater anticipated harm from drinking water, even when adjusting for indicators of water infrastructure and economic development. Disparities in anticipated harm across countries and by gender and household location indicate that targeted policies are required to address risk perceptions, equitably improve access to safe drinking water, and increase trust in institutions that supply and regulate water services. The addition of experiential survey data to global data collection efforts will complement objective water quality data and provide novel insights about which strategies will most effectively advance progress toward safe drinking water for all.

## Introduction

Water crises are endemic in most of the world and are increasing in both scope and severity due to mismanagement, agricultural and industrial pollution, climate change, and historic underinvestment in water treatment and distribution technologies<sup>1,6–9</sup>. Previous research has demonstrated the negative impacts of suboptimal water availability and accessibility on agricultural productivity<sup>10</sup>, economic development<sup>11</sup>, political stability<sup>12</sup>, and human well-being<sup>13</sup>, but the implications of poor water quality for these phenomena have been less well characterized. This is due, in part, to the lack of systematic monitoring and evaluation of the myriad known and emerging contaminants of concern, ranging from bacteria and viruses to pharmaceuticals and microplastics<sup>1,14,15</sup>. In fact, poor water quality has been referred to as an “invisible crisis” because many contaminants are not measured or detectable with current technologies<sup>1</sup>. Among the water indicators that are commonly tracked by governments and water agencies (e.g., turbidity, conductivity, nutrient concentration), most are reported at the nation or basin scale, which obscures inequalities by region, age, race, gender, class, and other sociodemographic characteristics<sup>4,16</sup>.

Objective measures of water quality (e.g., coliform bacteria concentration) are often poor predictors of consumption and use of water sources<sup>17,18</sup>. Survey data on human perceptions and experiences are increasingly appreciated for their ability to capture multiple factors that influence an individual's

behavior<sup>19</sup>. Regarding water quality, these include organoleptic properties (e.g., taste, smell); (dis)trust in local, regional, and national institutions; knowledge about and familiarity with water management and treatment practices; attitudes toward diverse contaminants; and the beliefs and values of those within an individual's social network<sup>3,20</sup>. Quantifying people's experienced and anticipated harm from drinking water in surveys is also useful because results can be disaggregated to the individual or household level<sup>21</sup>. As such, understanding human experiences with and anticipation of harm from drinking water is critical for designing programs and policies that aim to increase access to and use of safe drinking water.

Although safe drinking water is fundamental for health and well-being<sup>22,23</sup>, experienced and anticipated drinking water harm have not been systematically captured in a globally comparable way. For example, progress toward Sustainable Development Goal 6.1, "ensure availability and sustainable management of water and sanitation for all," is tracked by the WHO/UNICEF Joint Monitoring Programme (JMP), which assesses the proportion of the population using a safely managed drinking water source. A source is considered safe by the JMP if its design reduces the risk of bacterial contamination (i.e., an "improved source") and is free of both fecal coliforms and "priority" chemical contaminants<sup>24</sup>. These sentinel indicators represent only a small subset of the many potential contaminants that can render drinking water unsafe. Additionally, while these data provide critical information about inequities in water infrastructure availability, they do not offer insights into whether individuals trust and prefer these sources. Perception-based tools can complement these traditional water indicators by helping to inform where and how resources should be allocated to ensure equitable access to safe water and expand trust in water suppliers.

We therefore sought to provide the first global insights into the prevalence and predictors of self-reported experienced and anticipated drinking water harm using data from the Lloyd's Register Foundation 2019 World Risk Poll, a global survey designed to capture diverse perspectives on contemporary risks to human well-being. Specifically, we analyzed nationally representative data from 142 countries about experienced and anticipated harm from drinking water among adults in the prior and forthcoming two years. At the country level, we examined associations between anticipated harm from drinking water and physical water availability, drinking water infrastructure, gross domestic product (GDP) per capita, annual deaths attributable to unsafe water, and public sector corruption. At the individual level, we examined differences in anticipated harm from drinking water by gender and household location.

## Results

### Regional variations in water harm

In nationally representative survey data from 142 countries, 14.5% (95% CI: 14.1%, 15.0%) reported having personally experienced or knowing someone who had experienced serious harm from drinking water in the prior two years. The prevalence of reported harm from drinking water ranged from 0.8% in Singapore to 54.3% in Zambia (Figure 1, Extended Data Table 1). Regionally, experiences of harm attributed to unsafe drinking water were most common in Africa (Extended Data Figure 1).

More than half of the world's population (54.4%; 95% CI: 53.7%, 55.1%) anticipated experiencing serious harm in the next two years due to problems with drinking water (Figure 1). This ranged from 8.0% in Sweden to 78.3% in Lebanon (Extended Data Table 1). Anticipated harm was more geographically heterogeneous than experienced harm and was particularly high in Latin America, the Caribbean, Asia, and throughout Africa (Extended Data Figure 1). Experienced harm from drinking water only accounted for 39.4% of the variation in anticipated harm: each percentage point increase in the proportion of the population that reported experiencing harm from drinking water was associated with a 0.81 percentage point increase (95% CI: 0.65, 0.98) in the proportion of the population that anticipated harm (data not shown).

### **National trends in water harm**

To assess whether perception-based indicators offer novel insights into the global water crisis, we first explored if experienced and anticipated harm from drinking water were associated with traditional water indicators. In bivariate regression, national water availability, measured as cubic meters of renewable freshwater resources per capita, did not predict experienced or anticipated harm from drinking water (Figure 2A, Extended Data Table 2). For example, anticipated future drinking water harm was neither consistently high in countries where water is physically scarce, such as Saudi Arabia (72.5 m<sup>3</sup>/capita, 37.9% anticipated harm), nor low where water is more abundant, like Venezuela (27,389.9 m<sup>3</sup>/capita, 73.4% anticipated harm).

Greater access to improved drinking water infrastructure, measured as national coverage of “basic drinking water services” (i.e., water from an improved source that can be collected within 30 minutes roundtrip<sup>25</sup>), was associated with a lower proportion of individuals experiencing drinking water harm (Extended Data Table 2). There was no evidence of a linear relationship between basic drinking water access and anticipated drinking water harm (Figure 2B). Instead, we found that the prevalence of anticipated drinking harm was similar among countries where 95% or less of the population had access to basic drinking water services, but countries with more than 95% basic drinking water access had, on average, a lower prevalence of anticipated harm (B: -15.47; 95% CI: -20.32, -10.62). Among the 76 countries with high basic drinking water access, there was considerable heterogeneity in anticipated

harm. For instance, the populations of both Finland and Greece were estimated to have access to at least basic drinking water services, yet a far greater proportion of residents in Greece anticipated harm from their drinking water than those in Finland (58.9% vs. 9.1%). Similarly, the relationships between proportion of deaths attributable to unsafe water and both experienced and anticipated drinking water harm were not linear. Instead, there was indication of a threshold effect (Figure 2C). Countries with 1% or more of deaths attributable to unsafe water had, on average, a higher prevalence of experienced (B: 17.53, 95% CI: 14.29, 20.78) and anticipated harm (B: 11.85, 95% CI: 6.54, 17.17) compared to those with a lower proportion of deaths attributable to unsafe water.

Greater per capita GDP was associated with a lower proportion of the population reporting both experienced and anticipated harm from drinking water (Figure 2D, Extended Data Table 2). Within high-income countries, 37.2% of respondents anticipated harm from drinking water in the next two years; the proportion was uniformly high across upper middle- (54.8%), middle- (56.4%), and low-income (57.1%) countries.

We also sought to understand whether survey-based measures of water harm were correlated with the quality of public governance, as measured by the 2019 Corruption Perceptions Index (CPI). Lower perceived public sector corruption (i.e., higher CPI scores) was associated with both lower experienced and anticipated harm from drinking water (Figure 2E, Extended Data Table 2). For instance, 73.4% of residents in Yemen, the country with the highest observed level of corruption according to the CPI, anticipated future harm from their drinking water compared to only 11.4% in Denmark, assessed as the least corrupt country.

Multivariable models of experienced and anticipated drinking water harm were used to identify the most salient predictors of each. Lower access to basic drinking water sources, greater public sector corruption, and having 1% or more of deaths attributable to unsafe water were associated with greater reported drinking water harm (Extended Data Table 3). In contrast, corruption score was the only meaningful predictor of anticipated drinking water harm in a model adjusting for all national-level covariates: each one-point higher on the CPI was associated with a 0.45 percentage point lower (95% CI: -0.64, -0.26) proportion of individuals in a country anticipating harm from drinking water in the next two years.

## **Demographic trends in water harm**

Although anticipated harm from drinking water in the next two years was lowest in high- and upper middle-income countries, there was substantial variation within countries by gender and household

location (Figure 3, Extended Data Table 4). A greater proportion of women than men anticipated experiencing harm from drinking water in upper middle-income (61.4% vs. 52.8%) and high-income (43.0% vs. 32.0%) countries (Figure 3A). In contrast, anticipated harm did not meaningfully differ by respondent gender in low- and lower middle-income countries. Regarding household location, a lower proportion of rural households consistently anticipated harm from drinking water compared with those in urban or suburban areas across country income strata (Figure 3B). This difference was largest in lower middle-income (-7.3%) and upper middle-income countries (-9.7%).

## Discussion

These data, drawn from the first nationally representative assessment of experienced and anticipated drinking water safety, indicate that 54.4% of the global population, representing more than 4.2 billion individuals, anticipate being harmed by their drinking water in the next two years. This estimate is much higher than would be suggested by other global water indicators. As an example, WHO and UNICEF report that approximately one-quarter of the global population lacks access to safely managed drinking water<sup>25</sup>.

These findings are important because human behavior and health decision-making are largely driven by experiences, perceptions, and attitudes<sup>3,20</sup>. Individuals who perceive their water to be dangerous or of suboptimal quality are more likely to avoid or not pay for piped water<sup>26,27</sup>, consume bottled water<sup>28,29</sup>, and substitute sugar-sweetened beverages for water<sup>23,30</sup>, which in turn have negative consequences for the sustainability of water services as well as human and environmental well-being. Bottled water production, for instance, is a resource-intensive process that generates considerable greenhouse gas emissions and other contaminants that can pollute local water sources; it is also vastly more expensive than tap water and often of poorer quality<sup>31-33</sup>. Similarly, greater sugar-sweetened beverage intake increases the risk of dental caries, non-communicable diseases (e.g., diabetes), and may exacerbate dehydration<sup>34</sup>.

Differences in anticipated drinking water harm across countries were related to both structural and political conditions (Figure 2, Extended Data Table 2). For example, a greater proportion of the population reported likely future harm from drinking water in countries with lower GDP per capita. This is consistent with prior studies demonstrating that greater household income allows individuals to access higher quality water sources or purchase water treatment technologies<sup>35</sup>. Trust and governance are also critical elements of risk perception and water use, as demonstrated by the positive association between public sector corruption and anticipated drinking water harm. Interestingly, although basic drinking water services are estimated to have lower pathogen concentrations than surface water or unimproved sources<sup>24</sup>, JMP drinking water service level was only weakly associated with anticipated drinking water

harm (Extended Data Table 3). Further, in countries with more than 95% basic drinking water service coverage, there was considerable diversity in anticipated harm, supporting the notion that perceived risks are strongly influenced by factors other than objective water quality<sup>20</sup>.

These data suggest that addressing the global water crisis will require targeted interventions that address inequalities in access to safe drinking water and promote greater trust through improvements in water governance, knowledge dissemination, and relationship building<sup>36–38</sup>. For example, we found inequalities across country income levels and sociodemographic characteristics. Women reported similar or greater perceived future drinking water risk than men across country income levels, which may be due to gendered and class-related disparities in access<sup>39</sup>, greater awareness about a household's water situation (e.g., women are typically the main purveyors of water)<sup>40</sup>, or greater fears related to reproductive health<sup>41</sup>. Notably, while people living in urban areas typically have greater access to improved water sources than those in rural households<sup>25</sup>, they anticipated greater future drinking water harm (Figure 3). It is possible that urban households have greater access to media sources that report on water risks or are fearful about potential contamination from nearby factories and industries, which are more common in cities than in rural areas<sup>42</sup>. Additional research is ultimately needed to understand this seemingly paradoxical relationship.

It is evident that billions of individuals globally are concerned about their drinking water and its potential to cause serious harm. Although perceived risk varied by country, the prevalence of anticipated drinking water harm was high across all settings and sociodemographic characteristics. Emergent experiential evidence also demonstrates that issues with water access and use are common in both high-<sup>43</sup> and low-income settings<sup>4</sup>. Taken together, these findings underscore the substantial scope and magnitude of the global water crisis and its negative implications for health and well-being. A greater understanding of the types and concentration of water contaminants (existing and emerging), as well as relative trust in the institutions charged with their provision and regulation, is necessary to improve water quality both objectively and with respect to public perception. To help inform programs and policies that accomplish these aims, future research should concurrently collect data on objective water quality indicators – including citizen-science approaches that leverage rapid, cheap, easy-to-use point-of-use water diagnostics<sup>14</sup> – as well as information about perceived water risks and types of harm. Given the global consensus that drinking water is under threat, there is a clear need and substantial public will to invest in better water treatment and delivery systems that ensure water security for all<sup>44,45</sup>.

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## Methods

### Study sample

Data are drawn from the publicly available Lloyd's Register Foundation World Risk Poll, which was funded by the Foundation and implemented in 2019 by Gallup<sup>1</sup>. A national probability-based sample of approximately 1,000 individuals in each of 142 countries was randomly selected, consented, and interviewed by trained study staff. Exceptions were made for areas that posed safety threats to interviewers, and scarcely populated areas that could only be accessed by foot, animal, or small boat<sup>2</sup>. Ultimately, 154,195 participants were recruited. Due to their relative population sizes, samples were larger in some countries, such as China (N=3,709) and India (N=3,377), and smaller in others, such as Jamaica (N=501).

### Data collection

A full methodology report is available from the Lloyd's Register Foundation<sup>2</sup>. Briefly, phone surveys were conducted in countries in which telephone coverage was at least 80% or phone interviews were customary. Otherwise, face-to-face interviews were used. At least 15% of completed telephone interviews were checked by listening to interviews or recordings for quality control.

Sociodemographic characteristics and perceptions about risks from diverse sources were collected using a standardized questionnaire that was translated into the major languages of each country. Each survey version was validated through either comparing two independent translations or through a translation-back translation process.

### Outcomes: Experienced and anticipated harm

*Reported experienced harm* was assessed by asking participants whether they had experienced or personally knew someone who “experienced serious harm from drinking water in the past two years” (dichotomous: yes or no). *Anticipated harm* was assessed with a question that asked participants how likely it was that they would experience “serious harm in the next two years” from their drinking water. Response options were “not at all likely”, “somewhat likely”, and “very likely”. We created a binary variable of anticipated drinking water harm by combining “somewhat likely” and “very likely”.

## **National-level covariates**

To complement these data and explore associations with more commonly used water indicators, we leveraged other publicly available datasets. Estimates of national renewable freshwater resources (cubic meters per capita) in 2017 – the latest round of data currently available – were drawn from AQUASTAT, the Food and Agriculture Organization’s global information system on water and agriculture (N=141/142 countries in the World Risk Poll)<sup>3</sup>. We used nationally representative data about the proportion of households in each country with at least a basic drinking water service level (i.e., sources that have the potential to delivery safe water and require 30 minutes or fewer for roundtrip collection), estimated and reported by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation in 2019, as a proxy for water quality and access<sup>4</sup>. The proportion of deaths in a country attributable to unsafe water was approximated using data from the 2019 Global Burden of Disease Study (N=140/142 countries)<sup>5</sup>. Estimates of gross domestic product (GDP) per capita in 2019 (USD), as well as classifications of country income levels (low, lower middle, upper middle, and high), were retrieved from the World Bank database (N=142/142 countries)<sup>6</sup>. Finally, the 2019 Corruption Perceptions Index was used to estimate the perceived level of corruption in the public sector by key stakeholders within each country; potential scores range from 0-100, with lower scores indicating greater perceived corruption (N=141/142 countries)<sup>7</sup>.

## **Demographic covariates**

We explored how experienced and anticipated harm varied by individual-level characteristics that were included in the World Risk Poll and have been posited to be associated with harm from drinking water<sup>8,9</sup>. Covariates included self-reported gender, for which only two response options were available (dichotomous: male or female), and household location (dichotomous: “rural area, small town, or village” or “large city or suburb of a large city”)<sup>2</sup>.

## **Statistical analysis**

Respondent sampling weights were generated by Gallup statisticians to account for probability of selection into the study and ensure that the sample was projectable to the target population (i.e., representative of each nation) based on gender, age, and education or socioeconomic status (depending on data availability for each country)<sup>2</sup>. These projection weights were used to generate nationally representative, cross-culturally comparable estimates of the prevalence of experienced and anticipated drinking water harm in each country.

We first visualized trends between estimates of experienced and anticipated drinking water harm and national-level covariates to qualitatively assess their relationships. We then fitted regression models to determine whether there was evidence of linearity between each variable pair. Given that the distribution for access to basic drinking water services was negative skewed (i.e., many countries had >95% access to these services) and the distribution for deaths attributable to unsafe water was positive skewed (i.e., most countries had <1% of deaths attributed to unsafe water), we explored both variables as continuous and dichotomous predictors. The Akaike information criterion (AIC) was used to determine which variable form provided better model fit; lower AIC values indicate better fit. Basic drinking water sources was best modeled as a continuous predictor for experienced harm and dichotomous for anticipated harm; proportion of deaths attributable to unsafe water was best modeled as a dichotomous variable for both outcomes. To identify which factors were most salient for predicting experienced and anticipated harm from drinking water, we developed multivariable linear regressions for each outcome, using all country-level covariates as independent variables.

At the individual level, generalized linear models with binomial distributions and identity link functions were also used to estimate the prevalence difference between sociodemographic characteristics (respondent gender, household location) and perceptions about drinking water harm, stratified by World Bank country income classification.

All analyses were two-tailed tests ( $\alpha=0.05$ ) and completed using Stata 17.0 (StataCorp).

## Data availability

The datasets used for these analyses are publicly available. This includes data from the World Risk Poll (<https://wrp.lrfoundation.org.uk/data-resources/>), AQUASTAT (<http://www.fao.org/aquastat/statistics/query/index.html>), the Joint Monitoring Programme for Water Supply (<https://washdata.org/data/>), the Global Burden of Disease Study (<http://ghdx.healthdata.org/gbd-2019>), the World Bank (<https://data.worldbank.org/>), and Transparency International (<https://www.transparency.org/en/cpi/2019/index/nzl>).

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## Declarations

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### AUTHOR CONTRIBUTIONS

J.D.M., S.L.Y., and C.S. conceived the study. J.D.M. processed the data and performed all analyses. J.D.M. and S.L.Y. wrote the first draft. All authors contributed to data interpretation and provided revisions on subsequent versions of the manuscript.

### COMPETING INFORMATION DECLARATION

J.B.L. has a financial interest in Stemloop, Inc., which aims to commercialize rapid water quality diagnostics technologies. These interests were reviewed and managed by Northwestern University in accordance with their conflict of interest policies. All other authors declare no conflicts of interest.

### ADDITIONAL INFORMATION

Supplementary Information is available for this paper.

Correspondence and requests for materials should be addressed to Sera L. Young.

## Figures

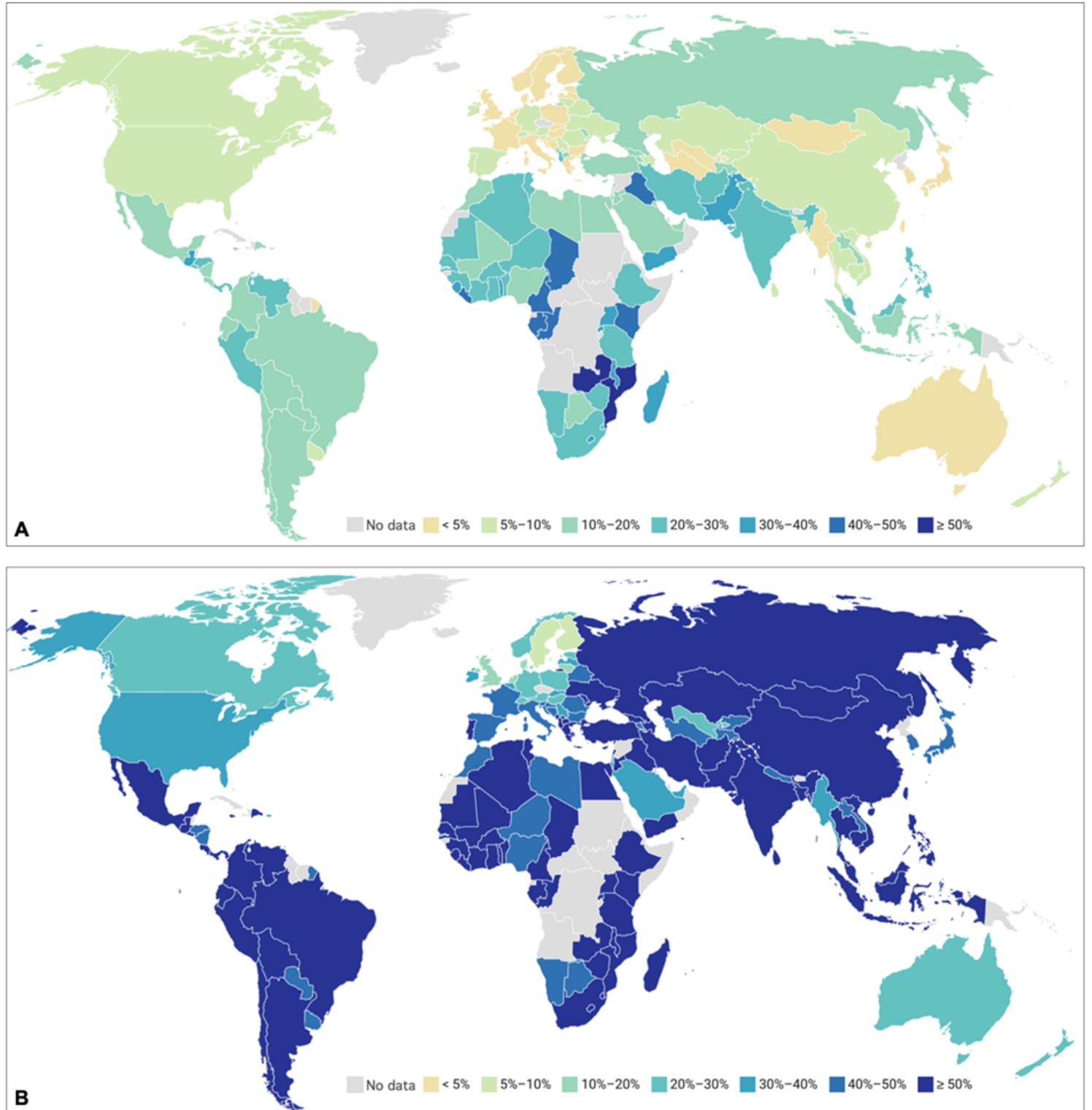
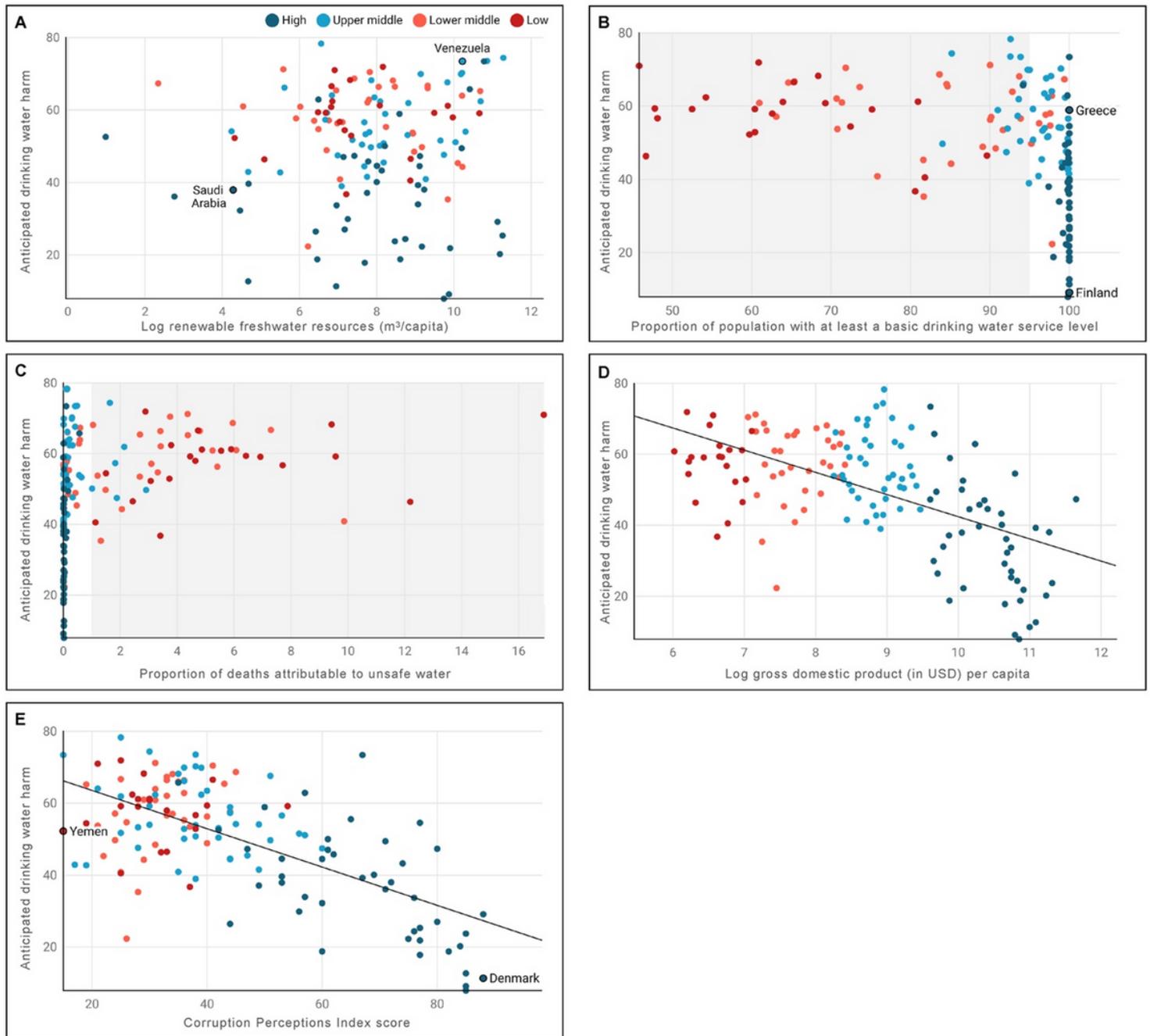


Figure 1

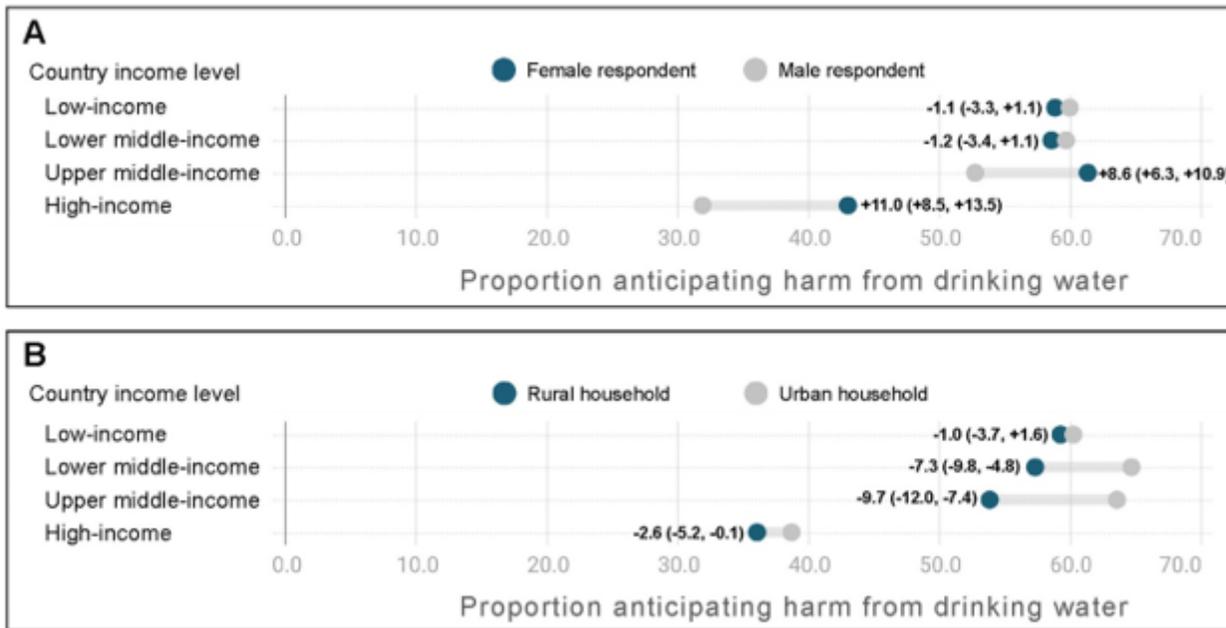
Proportion of population in 142 countries who (A) reported personally experiencing or knowing someone who experienced harm from drinking water in the prior two years or (B) anticipated experiencing harm from problems with drinking water in the next two years based on data from the Lloyd's Register Foundation 2019 World Risk Poll.



**Figure 2**

Proportion of the population in each country who anticipated harm from their drinking water in the next two years by (A) water availability (log renewable freshwater resources, m<sup>3</sup>/capita)46, (B) water infrastructure (proportion of population with at least a basic drinking water service level; shaded region represents countries with ≤95% access to these services)25, (C) water-related mortality (proportion of deaths in the country attributable to water; shaded region represents countries with ≥1% of deaths

attributable to unsafe water)<sup>47</sup>, (D) economic development (log gross domestic product per capita, USD)<sup>48</sup>, and (E) quality of public governance (Corruption Perceptions Index score)<sup>49</sup>. Model coefficients are in Extended Data Table 2.



**Figure 3**

Proportion of population in 142 countries in the Lloyd’s Register Foundation 2019 World Risk Poll who anticipated harm in the next two years due to problems with drinking water, by global region and (A) respondent gender and (B) household location. Percentage point differences in prevalence and 95% confidence intervals (in bold) were calculated using generalized linear models.

## Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [ExtendedData.docx](#)