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Self-reported anticipated harm from drinking water across 141 countries

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Perceptions of drinking water safety shape numerous health-related behaviors and attitudes, including water use and valuation, but they are not typically measured. We therefore characterize self-reported anticipated harm from drinking water in 141 countries using nationally representative survey data from the World Risk Poll (n = 148,585 individuals) and identify national- and individual-level predictors. We find that more than half (52.3%) of adults across sampled countries anticipate serious harm from drinking water in the next two years. The prevalence of self-reported anticipated harm is higher among women (relative to men), urban (relative to rural) residents, individuals with self-reported financial difficulties (relative to those getting by on their present income), and individuals with more years of education. In a country-level multivariable model, the percentage of the population reporting recent harm from drinking water, percentage of deaths attributable to unsafe water, and perceptions of public-sector corruption are associated with the prevalence of self-reported anticipated harm. Consideration of users' perspectives, particularly with respect to trust in the safety and governance of water services, is critical for promoting effective water resource management and ensuring the use, safety, and sustainability of water services.

Water crises are endemic in much of the world, and are increasing both in scope and severity[1,2]. Suboptimal water availability and accessibility are widespread issues[3,4] that have been shown to negatively impact agricultural productivity[5], economic development[6], conflict and regional stability[7], and human well-being[8–10]. The breadth of water quality issues and associated social and health consequences have been less well characterized[11]. This knowledge gap has been identified by the World Health Organization (WHO), the United Nations Children's Fund (UNICEF), and the World Bank as a barrier to generating global water safety estimates[12]. In the absence of reliable access to trusted information about water safety, individuals primarily make decisions about water use based on their perceptions and past experiences[13]. Importantly, though, individuals' lived experiences with water issues and perceptions about water hazards are not typically measured.

Drinking water service availability is the primary water indicator monitored by national statistical offices and global health agencies. The WHO and UNICEF track progress toward Sustainable Development Goal Target 6.1, "the proportion of the population using safely managed drinking water services", by estimating the proportion of households using "safely managed", "basic", "limited", or "unimproved" water services, which are classified based on the types of sources used, associated travel time to those sources, and the presence of priority biological and chemical contaminants[4]. Water quality data needed to

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measure progress toward Sustainable Development Goal 6.1, however, are available for less than half of the global population, such that access to at-least basic drinking water services is often reported and used for cross-country comparisons[4]. Further, even safely managed drinking water sources can have measurable levels of contaminants[14], and there is a growing number of emerging contaminants (e.g., microplastics, per- and polyfluoroalkyl substances) of public health concern that are not consistently monitored[15]. Water from safely managed sources can also become contaminated during transportation or storage, rendering it unsafe for consumption[16]. For example, jerrycans and other containers used to collect water can be a source of contamination if not regularly cleaned and maintained according to public health guidelines[17,18]. As such, current global water indicators do not capture all drinking water risks that may be of concern to consumers.

Data on water users' perspectives have the potential to complement and expand upon current water service indicators by capturing attitudes and beliefs that ultimately influence people's willingness to use, maintain, and pay for drinking water services[13]. For example, the United States is classified as having nearly universal safely managed drinking water services according to Sustainable Development Goal 6.1[19], yet millions of residents avoid tap water given well-documented cases of water system failure, such as lead contamination in Flint, Michigan[20,21] and water quality violations throughout Texas[22,23]. As a result, millions of individuals preferentially consume bottled water, which is more expensive and potentially of worse quality, long after acute water crises are resolved[24,25]. The perceived healthfulness of bottled water and its ability to confer higher social status in some contexts may also motivate bottled water use[13]. Additional documented determinants of individuals' water safety perceptions include organoleptic properties (e.g., taste, smell); (dis)trust of institutions; knowledge about water management and treatment practices; access to media; risk awareness and tolerance; and personal values and beliefs[13,26]. It is thus evident that factors beyond objective quality shape people's perceptions of water safety.

Believing that one's drinking water is harmful has substantial behavioral and health implications. Individuals who self-report exposure to unsafe water experience greater psychological stress (e.g., worry about ensuring sufficient water supplies for all household uses, anger at perceived governmental failure)[27] and are at greater risk of depression than those who do not[28]. Further, individuals who perceive their water to be of suboptimal quality are more likely to avoid or not pay for piped water, to consume bottled water, and to substitute sugar-sweetened beverages for water, compared to those who believe their water is safe[29–32]. These behaviors have negative impacts on the sustainability of public water services and human well-being, ranging from the pollution generated by production of packaged water and added financial stress from its purchase[33], to elevated risk of dental caries and other diseases (e.g., type 2 diabetes) associated with higher sugar-sweetened beverage intake[9]. Tools that capture individuals' subjective evaluations of their drinking water therefore have high utility for predicting water-related behaviors and assessing if the four pillars of water security—whether water is physically available, accessible, useable (i.e., whether individuals perceive water to be adequate for diverse needs), and reliable across time for all domestic uses[34]—are met. Indeed, quantification of perceptions has recently been demonstrated to predict a range of subsequent behaviors[35]. Measures of self-reported experiences can also be used to identify inequalities by urbanicity, gender, and other characteristics[36,37] to better target resources and develop tailored interventions that address the needs of consumers. Despite their value, data about perceived water safety and hazards have not been systematically collected.

We therefore sought to provide insights into the prevalence and predictors of self-reported drinking water risks across diverse settings. We used data from the Lloyd's Register Foundation 2019 World Risk Poll, which collected nationally representative data about perspectives on contemporary threats to human well-being. Specifically, we analyzed self-reports of harm attributed to drinking water in the prior year as well as harm anticipated to be experienced from drinking water in the forthcoming two years among non-institutionalized individuals aged 15 years and older. We aimed to (1) estimate the prevalence of self-reported harm from drinking water and concern about it, (2) assess country-level predictors that explained variation in the national prevalence of self-reported anticipated harm from drinking water, and (3) identify which individuals are most likely to perceive their water to be unsafe.

Results

Prevalence of self-reported and anticipated harm from drinking water

In nationally representative survey data from 142 countries collected through the Lloyd's Register Foundation World Risk Poll, 14.3% (95% CI: 13.6%, 15.0%) of individuals reported that they had personally experienced or knew someone who had experienced serious harm from drinking water in the prior two years (Fig. 1A). The prevalence of self-reported harm from drinking water ranged from 0.9% in Singapore to 54.3% in Zambia (Supplementary Data 1). We estimated that more than half of individuals across 141 sampled countries (52.3%; 95% CI: 51.2%, 53.4%) anticipate experiencing serious harm from drinking water in the next two years (Fig. 1B). The prevalence of anticipated harm from drinking water ranged from 8.0% in Sweden to 78.3% in Lebanon. Data about anticipated harm from drinking water were missing for Kuwait.

Country-level predictors of anticipated drinking water harm

To assess whether perception-based indicators offer insights into water insecurity, we first explored if the prevalence of self-reported anticipated harm from drinking water was associated with traditional supply-side indicators aggregated at the country level. National water availability (m^3 renewable freshwater resources per capita) was not statistically significantly associated with prevalence of self-reported anticipated harm from drinking water in a bivariate weighted least squares regression with robust standard errors [Fig. 2A, Table 1; β (95% CI): 0.2 (−1.5, 1.9); $p = 0.819$]. Prevalence of self-reported anticipated drinking water harm was neither consistently high in countries where water is physically scarce, such as Saudi Arabia (72.5 m^3/capita, 37.9% anticipated harm), nor low where water is abundant, as in Venezuela (27,389.9 m^3/capita, 73.4% anticipated harm).

The percentage of national coverage of at-least basic drinking water services explained 23.4% of the variation in prevalence of self-reported anticipated harm from drinking water (Table 1). The relationship was nonlinear [$\beta_{\text{quadratic term}}$ (95% CI): −0.02 (−0.04, −0.01); $p < 0.001$], although in general, prevalence of self-reported anticipated harm from drinking water was lower at the highest levels of basic drinking water service coverage (Fig. 2B). There was heterogeneity among the 76 countries with greater than 95% access to basic drinking water services. For instance, the entire populations of Finland and Greece were estimated to have access to at-least basic drinking water services, yet a much greater percentage of respondents in Greece anticipated harm from their drinking water (58.9%) than those in Finland (9.1%).

Wastewater treatment is a process that protects surface water and groundwater from contaminants, thereby shaping drinking water quality[38]. Primary wastewater treatment removes large solids, secondary treatment involves use of microorganisms to remove dissolved and suspended organic matter, and tertiary treatment reduces the concentration of inorganic compounds[39]. Among World Risk Poll respondents across 141 countries, the percentage of domestic and manufacturing wastewater that was treated nationally (aggregated across the three treatment forms) was, in general, negatively associated with prevalence of self-reported anticipated drinking water

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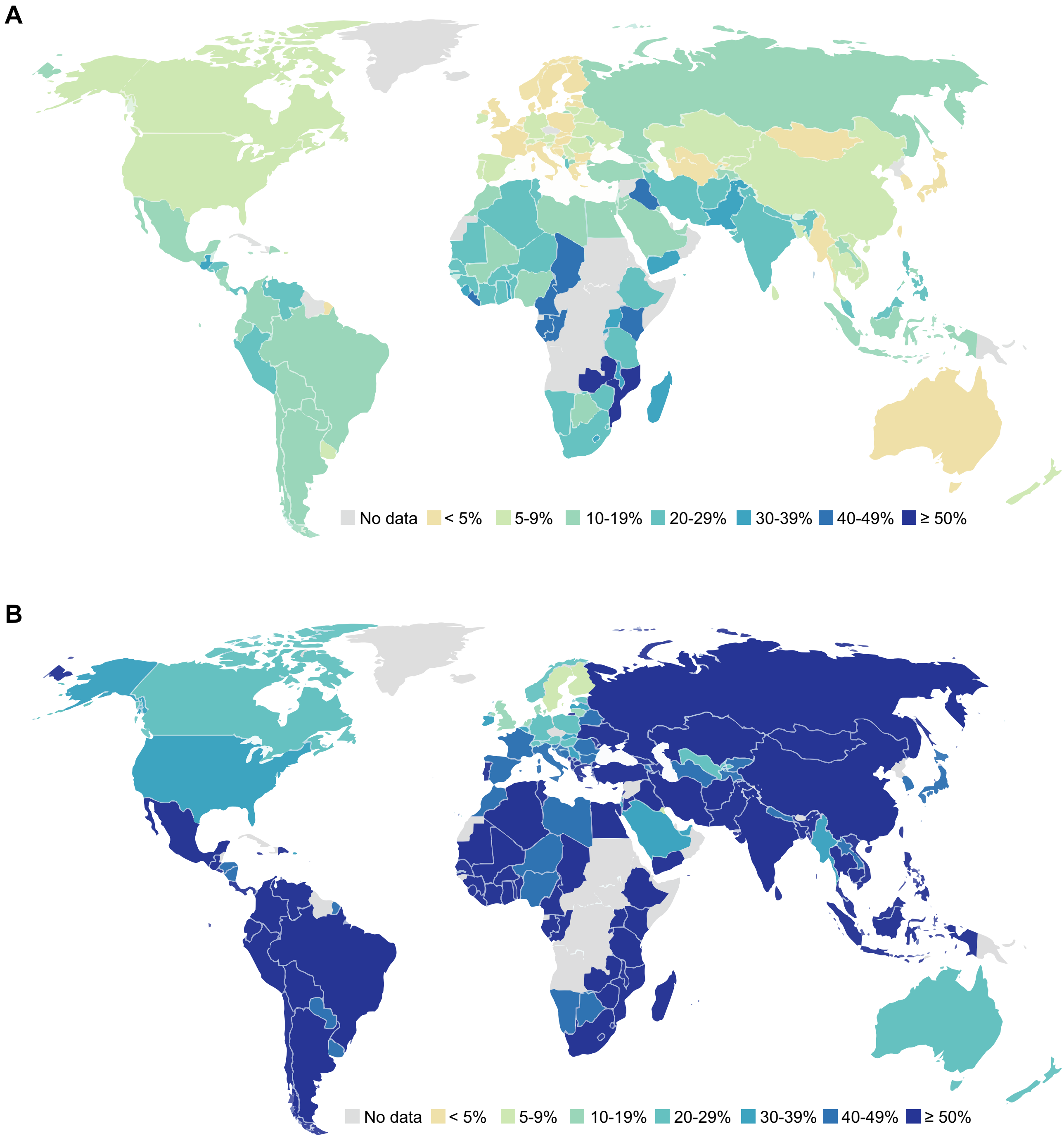

Fig. 1 | Prevalence of self-reported experienced and anticipated harm from drinking water. Percentage of the population in countries that (**A**) reported personally experiencing or knowing someone who experienced harm from drinking water in the prior two years ($N = 142$ countries) and (**B**) anticipated experiencing serious harm from drinking water in the next two years ($N = 141$ countries), based on data from the Lloyd's Register Foundation 2019 World Risk Poll. Point estimates provided in Supplementary Data 1.

harm [$\beta_{quadratic\ term}$ (95% CI): −0.004 (−0.006, −0.001); $p = 0.003$], explaining 36.6% of variation in responses (Fig. 2C, Table 1).

To explore the association between indicators of water quality and perceptions of drinking water harm, we used available data about the percentage of drinking water sources estimated to be contaminated with *Escherichia coli*, an indicator organism for pathogenic water contamination that contributes substantially to the global burden of diarrheal disease[40]. In the 23 countries in the World Risk Poll for which nationally representative data on the presence of *Escherichia coli* in a household's primary water source were available, there was no statistically significant association between percentage of the population using contaminated drinking water and prevalence of self-reported anticipated drinking water harm [Fig. 3; β (95% CI): −0.1 (−0.3, 0.1); $p = 0.215$].

Prevalence of self-reported experienced harm to self or others from drinking water in the prior two years explained 52.9% of the variation in the prevalence of anticipated future harm from drinking water (Table 1). The relationship was curvilinear [$\beta_{quadratic\ term}$ (95% CI): −0.03 (−0.04, −0.02); $p < 0.001$]: percentage of individuals reporting prior harm from drinking water was generally positively associated with percentage of individuals anticipating serious future harm from drinking water, but among countries with greater than 40% of the

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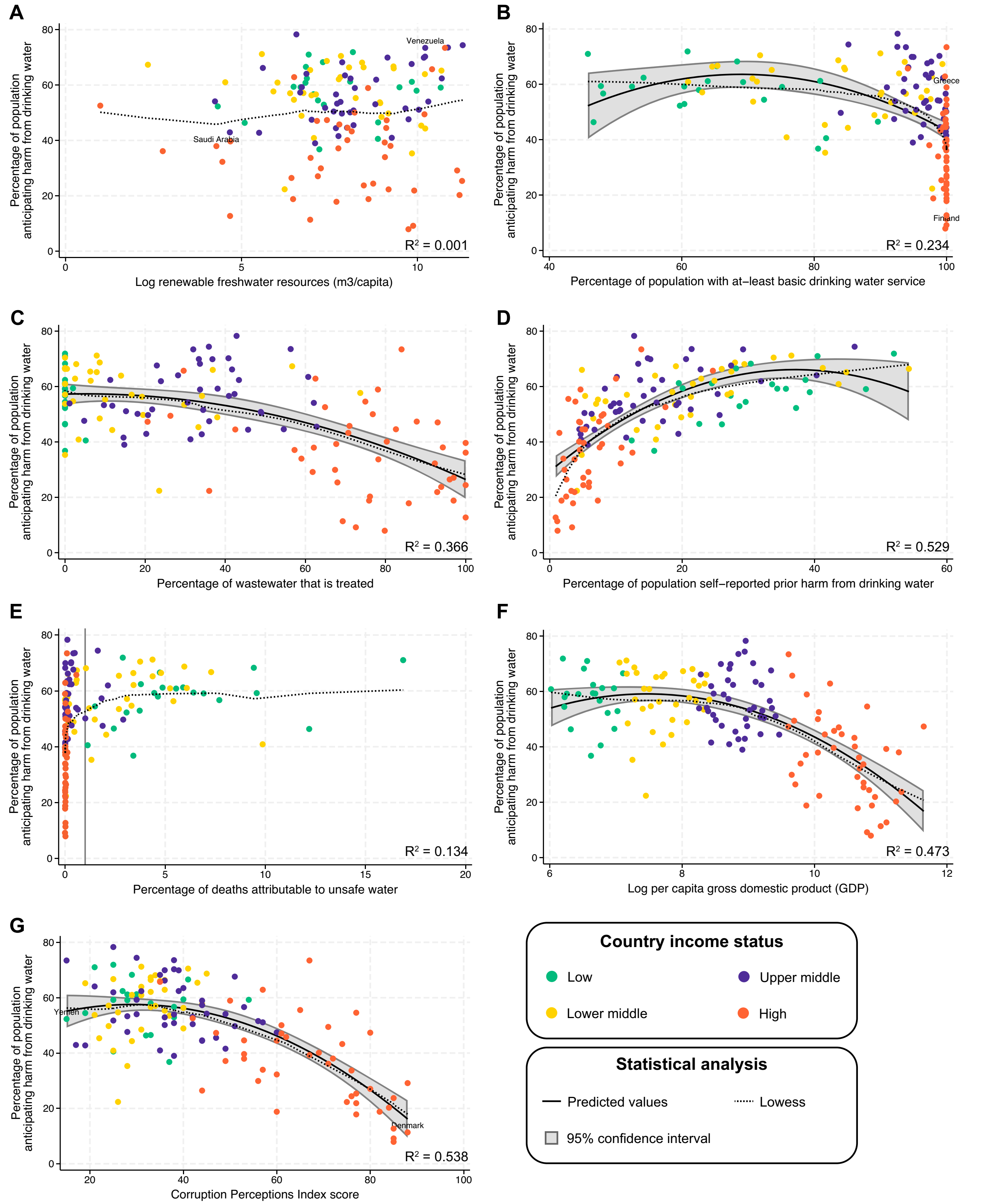

Fig. 2 | Country-level predictors of concern about drinking water. Percentage of the population in each country that anticipated harm from their drinking water in the next two years in 2019 by **A** water availability (log renewable freshwater resources, m^3/capita) in 2017 (N = 136 countries)[72], **B** water infrastructure (percentage of population with at-least a basic drinking water service level) in 2019 (N = 135 countries)[4], **C** percentage of wastewater that was treated in 2015 (N = 137 countries)[73], **D** self-reported experienced drinking water harm in 2019 (N = 141 countries), **E** water-related mortality (percentage of deaths in the country attributable to water; shaded region represents countries with ≥1% of deaths attributable to unsafe water) in 2019 (N = 138 countries)[74], **F** economic development (log gross domestic product per capita, USD) in 2019 (N = 137 countries)[75], and **G** quality of public governance (Corruption Perceptions Index score) in 2019 (N = 140 countries)[41]. Model coefficients and 95% confidence intervals are in Table 1. Data are presented as observed values (circles) and predicted values (black line) with associated 95% confidence intervals (gray area) based on fitted weighted least squares regressions with robust standard errors. Tests were two-tailed.

Table 1 | Bivariate weighted least squares regressions of the national prevalence of self-reported anticipated harm from drinking water in the next two years across 141 countries in the Lloyd's Register Foundation 2019 World Risk Poll

	Number of countries	β (95% CI)	p value	R^2
Per capita log renewable freshwater resources	136	0.2 (−1.5, 1.9)	0.819	0.001
Percentage of population with basic drinking water service level	135			0.234
Linear term		3.3 (1.4, 5.2)	0.001	
Quadratic term		−0.02 (−0.04, −0.01)	<0.001	
Percentage of wastewater that is treated	137			0.366
Linear term		0.02 (−0.2, 0.2)	0.849	
Quadratic term		−0.004 (−0.006, −0.001)	0.003	
Percentage of population self-reporting experiences of harm from drinking water in prior 2 years	141			0.529
Linear term		2.1 (1.6, 2.7)	<0.001	
Quadratic term		−0.03 (−0.04, −0.02)	<0.001	
≥1% of deaths attributable to unsafe water (ref: <1%)	138	12.6 (7.8, 17.3)	<0.001	0.134
Log per capita GDP	137			0.473
Linear term		40.3 (21.4, 59.1)	<0.001	
Quadratic term		−2.7 (−3.8, −1.6)	<0.001	
Corruption Perception Index score (range: 0–100)	140			0.538
Linear term		0.7 (0.1, 1.3)	0.020	
Quadratic term		−0.01 (−0.02, −0.01)	<0.001	

β beta coefficient, *95% CI* 95% confidence interval.

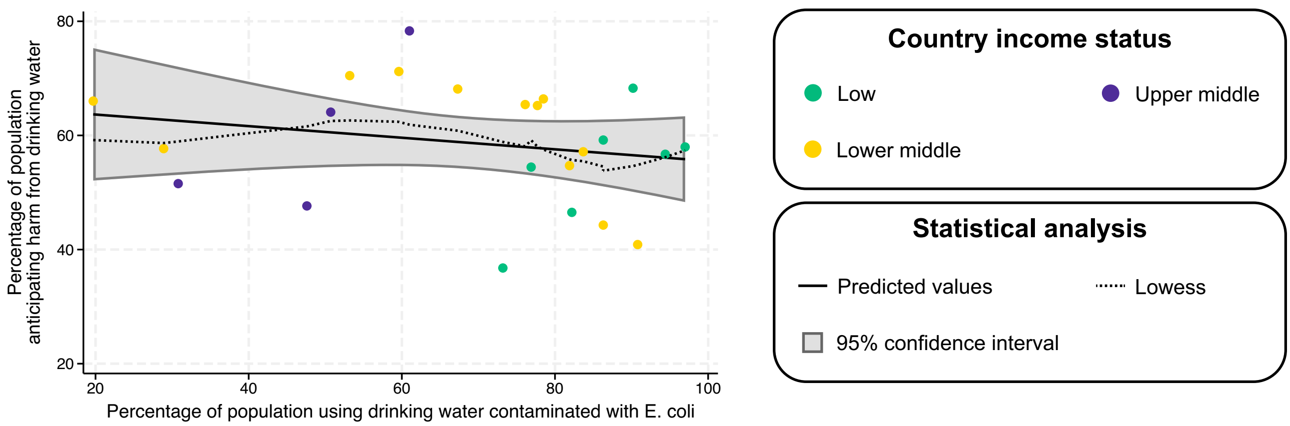

Fig. 3 | Association between drinking water contamination and self-reported anticipated harm from drinking water. Percentage of the population in 23 countries who anticipated harm from their drinking water in the next two years (measured in 2019), by the percentage of the population estimated to be using drinking water contaminated with *Escherichia coli* at the point of use (measured between 2012 and 2019). Data are presented as observed values (circles) and predicted values (black line) with associated 95% confidence intervals (gray area) based on a fitted weighted least squares regression with robust standard errors. The statistical test was two-tailed.

population reporting prior harm from drinking water, the inverse was observed (Fig. 2D).

The percentage of deaths attributable to unsafe water was positively associated with prevalence of self-reported anticipated drinking water harm (Fig. 2E). On average, a greater percentage of respondents in countries with 1% or more of annual deaths attributable to unsafe water anticipated harm from drinking water compared to those with fewer relative water-related deaths [β (95% CI): 12.6 (7.8, 17.3); $p < 0.001$]. Nevertheless, it is notable that a high percentage of respondents from countries with less than 1% of annual deaths attributable to unsafe water anticipated future harm. For example, ~0.1% of deaths in Lebanon were attributable to water, but 78.3% of respondents from that country anticipated future drinking water harm.

Greater logged per capita gross domestic product (GDP) was associated with a lower percentage of the population reporting anticipated harm from drinking water [$\beta_{\text{quadratic term}}$ (95% CI): −2.7 (−3.8, −1.6); $p < 0.001$], explaining 47.3% of variation in the outcome (Fig. 2F, Table 1). Within high-income countries, 37.2% of respondents anticipated harm from drinking water in the next two years; the percentage was similarly high across upper middle- (54.8%), middle- (56.4%), and low-income (57.1%) countries.

Finally, we sought to understand whether prevalence of self-reported anticipated harm from drinking water was correlated with the perceived quality of public governance. Lower corruption (i.e., higher Corruption Perceptions Index scores[41]) was associated with lower self-reported anticipated harm from drinking water [Fig. 2G, Table 1; $\beta_{\text{quadratic term}}$ (95% CI): −0.01 (−0.02, −0.01); $p < 0.001$] and independently explained the greatest variation in prevalence of anticipated harm from drinking water (53.8%) relative to other examined factors. For example, in Yemen, the country with the greatest perceived corruption, 52.3% of individuals anticipated future harm from drinking water compared to only 11.4% in Denmark, assessed as the least corrupt country. While public sector corruption explained a large amount of variation in self-reported anticipated harm, other factors clearly shape the conceptualization of drinking water risks. For instance, 62.3% (95% CI: 60.9%, 63.7%) of individuals who anticipated harm from their drinking water in the next two years also affirmed that their government did a "good job" ensuring safe drinking water.

Country-level characteristics were included in a multivariable regression to identify the most salient predictors of the prevalence of self-reported anticipated harm from drinking water. Prevalence of self-reported experienced harm to self or others from drinking water in the prior two years [$\beta_{\text{quadratic term}}$ (95% CI): −0.02 (−0.03, −0.01); $p = 0.001$], having 1% or more of annual deaths attributable to unsafe water [β (95% CI): −5.9 (−11.5, −0.02); $p = 0.042$], and public sector corruption score [$\beta_{\text{quadratic term}}$ (95% CI): −0.01 (−0.02, −0.01); $p < 0.001$] were associated with prevalence of self-reported anticipated harm (Table 2). Model results suggest that a country with a Corruption Perceptions Index score of 80 (range: 0–100, with higher scores indicating lower perceived corruption) would be expected to have a 16.6-percentage-point lower (95% CI: −27.5, −5.3; $p = 0.003$) prevalence of self-reported anticipated future harm from drinking water than a country with a score of 60, with all other characteristics being identical. Interestingly, the direction of association between percentage of annual deaths attributable to unsafe water and the prevalence of self-reported anticipated harm changed when adjusting for all covariates. The multivariable model explained 74.8% of the variation in prevalence of self-reported anticipated harm from drinking water.

Table 2 | Multivariable weighted least squares regression of the national prevalence of self-reported anticipated harm from drinking water in the next two years across 141 countries in the Lloyd's Register Foundation 2019 World Risk Poll

	β (95% CI)	p value
Per capita log renewable freshwater resources	0.9 (−0.2, 1.9)	0.109
Percentage of population with basic drinking water service level		
Linear term	0.4 (−1.3, 2.0)	0.660
Quadratic term	−0.003 (−0.01, 0.008)	0.583
Percentage of wastewater that is treated		
Linear term	0.1 (−0.09, 0.3)	0.253
Quadratic term	−0.001 (−0.004, 0.001)	0.289
Percentage of population self-reporting experiences of harm from drinking water in prior 2 years		
Linear term	1.5 (1.0, 2.1)	<0.001
Quadratic term	−0.02 (−0.03, −0.01)	0.001
≥1% of deaths attributable to unsafe water (ref: <1%)	−5.9 (−11.5, −0.2)	0.042
Log per capita GDP		
Linear term	7.1 (−19.5, 33.7)	0.597
Quadratic term	−0.3 (−1.9, 1.3)	0.715
Corruption Perception Index score (range: 0–100)		
Linear term	0.8 (0.3, 1.4)	0.003
Quadratic term	−0.01 (−0.02, −0.01)	<0.001
Number of countries	130	
R^2	0.748	

β beta coefficient, *95% CI* 95% confidence interval.

Individual-level predictors of anticipated drinking water harm

Self-reported anticipated harm from drinking water varied by demographic characteristics within national income strata (Tables 3 and 4) and across countries (Supplementary Figs. 1–4). Across sites in bivariate models, a greater percentage of women [prevalence difference (PD) (95% CI): 4.9 percentage points (pp) (3.4pp, 6.3pp); $p < 0.001$], individuals reporting difficulty getting by on their income [PD (95% CI): 4.1pp (2.5pp, 5.6pp); $p < 0.001$], urban residents [PD (95% CI): 5.1pp (3.1pp, 7.1pp); $p < 0.001$], and college-educated individuals [PD (95% CI): 10.9pp (8.4pp, 13.5pp); $p < 0.001$] reported anticipating harm from drinking water in the next two years compared to men, individuals reporting no difficulty getting by on their income, rural residents, and individuals with less than a high school education, respectively (Table 3). In a multivariable model, all factors were similarly associated with self-reported anticipated harm from drinking water (Table 3).

Associations between individual-level characteristics and self-reported anticipated harm from drinking water were modified by national income level (Supplementary Tables 1–4). For instance, there were no statistically significant differences in anticipated harm by gender in low- [PD (95% CI): −1.0 (−3.2, 1.3); $p = 0.399$] and lower middle-income countries [PD (95% CI): −1.0 (−3.4, 1.4); $p = 0.412$], but a greater percentage of women were estimated to anticipate harm from drinking water in upper middle- [PD (95% CI): 8.5pp (5.8pp, 11.2pp); $p < 0.001$] and high-income countries [PD (95% CI): 10.5pp (8.2pp, 12.8pp); $p < 0.001$] (Table 4, Fig. 4). Importantly, observed differences were heterogenous across countries (Supplementary Fig. 1). For instance, the percentage of women anticipating harm from drinking water was 19.2-pp higher than that of men in Moldova, but 11.6-pp lower in Nigeria.

A greater percentage of individuals reporting difficulty getting by on their income were estimated to anticipate future drinking water harm in low- [PD (95% CI): 5.4pp (2.8pp, 7.9pp); $p < 0.001$], upper middle- [PD (95% CI): 5.4pp (2.7pp, 8.0pp); $p < 0.001$], and high-income countries [PD (95% CI): 13.7pp (10.4pp, 17.1pp); $p < 0.001$] compared to their counterparts who were able to get by on their income (Table 4, Fig. 4). The prevalence of anticipated harm from drinking water differed by urbanicity in lower [PD (95% CI): 6.4pp (3.0pp, 9.9pp); $p < 0.001$] and upper middle-income countries [PD (95% CI): 6.5pp

Table 3 | Percentage-point differences in prevalence of self-reported anticipated harm from drinking water across 141 countries in the Lloyd's Register Foundation 2019 World Risk Poll, by demographic characteristics (*n* = 147,555 individuals)

	Self-reported anticipated harm from drinking water			
	Bivariate		Multivariable	
	PD (95% CI)	p value	PD (95% CI)	p value
Woman (ref: man)	4.9 (3.4, 6.3)	<0.001	5.5 (4.0, 6.9)	<0.001
Difficult to get by on present income (ref: getting by on present income)	4.1 (2.5, 5.6)	<0.001	6.0 (4.5, 7.5)	<0.001
Urban location (ref: rural location)	5.1 (3.1, 7.1)	<0.001	4.1 (2.3, 5.9)	<0.001
Education (ref: up to 8 years)				
9–15 years	7.7 (6.1, 9.4)	<0.001	8.7 (7.0, 10.5)	<0.001
Four or more years beyond high school	10.9 (8.4, 13.5)	<0.001	11.9 (9.5, 14.4)	<0.001

Point estimates and 95% confidence intervals were calculated using weighted generalized linear models with binomial distributions, identity link functions, and country membership included as a fixed effect.
PD prevalence difference, *95% CI* 95% confidence interval.

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Table 4 | Percentage-point differences in prevalence of self-reported anticipated harm from drinking water across 141 countries in the Lloyd's Register Foundation 2019 World Risk Poll, by country income status and demographic characteristics

	Self-reported anticipated harm from drinking water							
	Low-income countries (n = 21,287 individuals)		Lower middle-income countries (n = 36,197 individuals)		Upper middle-income countries (n = 46,935 individuals)		High-income countries (n = 43,136 individuals)	
	PD (95% CI)	p value	PD (95% CI)	p value	PD (95% CI)	p value	PD (95% CI)	p value
Woman (ref: man)	−1.0 (−3.2, 1.3)	0.399	−1.0 (−3.4, 1.4)	0.412	8.5 (5.8, 11.2)	<0.001	10.5 (8.2, 12.8)	<0.001
Difficult to get by on present income (ref: getting by on present income)	5.4 (2.8, 7.9)	<0.001	−0.6 (−3.1, 2.0)	0.666	5.4 (2.7, 8.0)	<0.001	13.7 (10.4, 17.1)	<0.001
Urban location (ref: rural location)	0.7 (−2.4, 3.7)	0.664	6.4 (3.0, 9.9)	<0.001	6.5 (2.7, 10.2)	0.001	1.7 (−0.8, 4.2)	0.178
Education (ref: up to 8 years)								
9–15 years	6.1 (3.7, 8.5)	<0.001	4.8 (1.9, 7.6)	0.001	10.7 (8.0, 13.4)	<0.001	3.8 (0.2, 7.4)	0.039
Four or more years beyond high school	13.2 (8.3, 18.1)	<0.001	15.9 (12.4, 19.4)	<0.001	16.5 (12.1, 20.9)	<0.001	−1.3 (−5.2, 2.6)	0.514

Point estimates and 95% confidence intervals were calculated using weighted bivariate generalized linear models with binomial distributions, identity link functions, and country membership included as a fixed effect.
PD prevalence difference, *95% CI* 95% confidence interval.

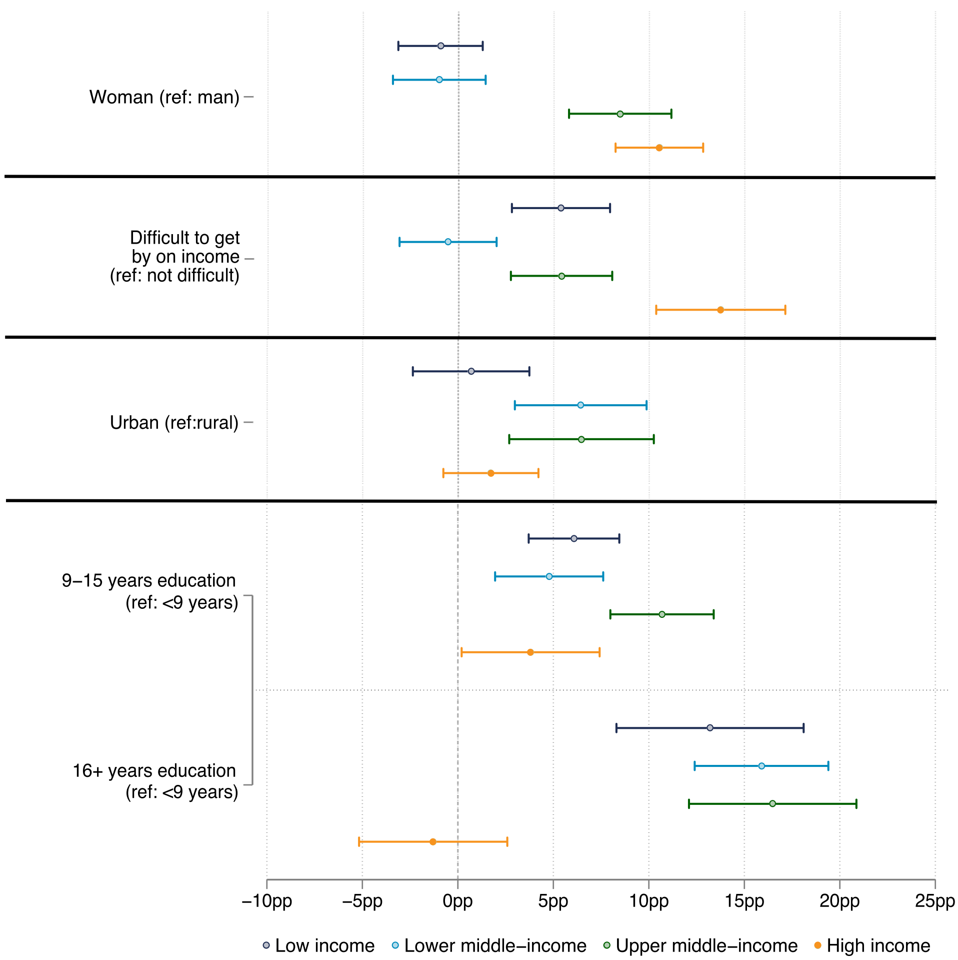

Fig. 4 | Differences in self-reported anticipated harm from drinking water by demographic characteristics. Estimated percentage point (pp) differences in prevalence of anticipated drinking water harm among individuals in 141 countries, by gender, difficulty getting by on income, urbanicity, and years of education, across national income strata (n = 147,555 individuals). Model coefficients and 95% confidence intervals are in Table 4. Data are presented as point estimates (circles) and associated 95% confidence intervals (capped lines) based on generalized linear models with binomial distributions and the identity link function. Tests were two-tailed.

(2.7pp, 10.2pp); $p = 0.001$], but not in low- [PD (95% CI): 0.7pp (−2.4pp, 3.7pp); $p = 0.664$] or high-income countries (PD (95% CI): 1.7pp (−0.8pp, 4.2pp); $p = 0.178$]. In contrast, greater education was consistently associated with higher prevalence of self-reported anticipated harm across income strata, except in high-income countries. The magnitude of association was high. In upper middle-income countries, for instance, the prevalence of anticipated harm was estimated to be 16.5-pp higher (95% CI: 12.1pp, 20.9pp; $p < 0.001$) among individuals with four or more years of education beyond high school compared to those with 8 or fewer years of education. In multivariable models, most factors were similarly associated with self-reported anticipated harm from drinking water (Supplementary Table 5).

In a multilevel mixed-effects model, individual- and country-level factors were associated with anticipated harm from drinking water in similar directions as observed in the separate multivariable models, except percentage of deaths within a country attributable to unsafe water (Supplementary Table 6). For instance, the odds of anticipating harm from drinking water was 1.25 times higher (95% CI: 1.22, 1.28; $p < 0.001$) among women compared to men. Further, individuals who reported experiencing or personally knowing someone who experienced serious harm from drinking water in the prior two years had 4.23 times the odds (95% CI: 4.07, 4.39; $p < 0.001$) of anticipating harm from drinking water compared to those who did not.

Discussion

These nationally representative data, drawn from a survey on public perceptions of drinking water, indicate that an estimated 52.3% of individuals from 141 countries believe that they are likely to be harmed by their drinking water in the next two years. This estimate is higher and more geographically heterogenous than would be expected if risk perceptions tracked objective global water quality or income data[4]. The high prevalence of self-reported anticipated harm is consistent with emergent experiential evidence that issues with water availability, accessibility, use, and stability are common in both high-[42] and low- and middle-income settings[3,43]. Widespread self-reported anticipated harm from drinking water is likely multi-factorial and may be, in part, a response to projected threats to water quality and the sustainability of water services, including the ability to keep water sources safe from microbial and chemical contamination under conditions of worsening climate change[44], although such data were not collected in this study.

Significant country-level predictors of greater anticipated harm from drinking water included higher prevalence of self-reported harm attributed to poor drinking water, more deaths attributable to unsafe water, and greater perceived public sector corruption. These findings align with national or sub-national studies that have found that drinking water appraisal is largely driven by experiences, perceptions, and attitudes[13,26]. Indeed, prior research has demonstrated that individuals who have experienced adverse consequences of an environmental hazard (e.g., flooding) are more likely to have stronger risk perceptions of that hazard[45,46].

The association between self-reported anticipated harm and perceived public corruption may be partially explained by a decades-long decline in general trust in public institutions which, tellingly, is tracked in some locations by changes in bottled water consumption[47]. Relatedly, trust in the capabilities and will of political institutions and leaders may influence risk perceptions, which are strongly and consistently associated with each other[48]. For instance, a study in Australia found that political outlook influenced support for a local potable water recycling scheme[49]. Similarly, a study in the Netherlands found that generalized political trust was the strongest predictor of trust in water managers[50]. Importantly, we found that nearly two-thirds of individuals who anticipated harm from their drinking water in the next two years also affirmed that their government did a “good job” ensuring safe drinking water. This suggests that individuals may believe that their governments are setting appropriate regulations but distrust their implementation, enforcement, and uptake by water utilities, which may be managed by private businesses.

Improving public trust in the safety of drinking water will require better data, appropriate messaging, and programs that acknowledge and effectively respond to widespread safety concerns. These measures include improvements in transparency about and actions to address issues with water management and the presence of contaminants of concern, as well as relationship building across utilities, national and local governments, public health agencies, and water users to improve water system trustworthiness[51,52]. For example, 20% of participants enrolled in a study in the Netherlands reported that there was insufficient information provided about tap water quality, which contributed to feelings of distrust and increased bottled water use[53]. Numerous projects have used the Integrated Water Resources Management framework, which emphasizes public engagement and participation, to expand access to critical water services[54]. Although procedures for implementing the Integrated Water Resources Management framework have been criticized for being poorly defined[55], the process has been demonstrated to improve trust in water resources and democratize water management if local communities are meaningfully involved at all stages of development[56,57]. Large-scale reforms beyond the water sector, including reduction in economic disparities and greater accountability for corrupt actors, may also increase trust and should be tested[47]. To help develop and evaluate programs and policies that accomplish these aims, objective data on water quality as well as information about experiences with and anticipated harm from drinking water should be collected concurrently[43]. Such information has been found to be useful for predicting public acceptance of new water schemes, such as use of recycled water[58], as well as trust in community water sources following disease outbreaks[59].

Interventions tailored to individuals anticipating greater harm are also needed. For example, women reported similar or greater perceived future drinking water risk than men across income strata; this may be due to gendered disparities in access[60] or greater awareness about a household’s water risk situation, as women are typically the managers of domestic water[61]. Urban residents anticipated greater drinking water harm, although they typically have greater access to improved water sources than rural households[4]. This seemingly paradoxical relationship may be explained by the fact that urban households have greater access to information about water, may be closer to industrial contamination sites, and may be more severely impacted by poorly managed waste systems[62]. Moreover, they may have less access to alternative water supplies (e.g., rainwater capture, private wells) than rural residents. Programs that address drinking water disparities by, for example, equitably expanding access to and information about safe and trusted water could be beneficial[63], as could interventions that mitigate exposure to environmental contaminants via other pathways (e.g., poor hygiene, air pollution) that individuals may attribute to unsafe drinking water. For example, in the United States, where drinking water service disparities are largely a product of environmental racism and discriminatory housing policies[64], replacement of lead pipes and the provision of at-home water filters may decrease harm from water and bolster trust in water services. Given that country income level modified the strength of the relationships between each demographic characteristic and anticipated harm, a uniform approach cannot be taken when addressing concerns over drinking water.

The ability to compare perceptions about the potential for serious harm from drinking water across diverse settings expands our understanding of the global water crisis and consumer concerns. Self-reported anticipated drinking water harm does not, however, always translate to future hazard occurrence—it is unlikely that all who anticipate harm will experience harm. A further limitation of these data is that self-reported experienced or anticipated harm from drinking water may be attributable to numerous causes beyond water, including other environmental conditions (e.g., air pollution, food contamination). Despite this, the fact that individuals believe that they have been or may be harmed by drinking water is meaningful because these perceptions shape attitudes and health-related behaviors[26,65,66]. Importantly, as with all surveys, there is potential for self-selection bias. Gallup, which conducted the World Risk Poll on behalf of the Lloyd's Register Foundation, addresses these issues through rigorous sampling protocols and post-stratification weighting, but such methods may not fully resolve this concern. In addition, these data provide only one snapshot in time. We therefore encourage researchers to examine these trends longitudinally to identify causal relationships and understand how consumers' perspectives are shifting, especially in the context of climate change and in relation to diverse objective measures of water quality. More rigorous analyses at the country and sub-national levels are also needed to understand context-specific drivers of risk perceptions about water harms and other hazards queried about in the World Risk Poll (e.g., food safety, severe weather events). Finally, the Corruption Perceptions Index only assesses perceived public sector corruption. Future work should examine how perceived corruption of private sector actors, particularly those involved with the management and provision of water, influences drinking water risk assessments.

Taken together, these findings suggest that the prevalence of anticipated harm from drinking water is high across diverse populations, geographies, and water service levels. Anticipated harm from drinking water is an underappreciated aspect of the global water crisis that may have myriad negative implications for health and well-being. There is clear need to consider users' perspectives to promote water security and ensure the safety, use, and sustainability of water services.

Methods

Inclusion and ethics

This research complies with all relevant ethical regulations. We used deidentified data from Lloyd's Register Foundation World Risk Poll for these analyses. These data were collected by Gallup, and survey procedures were approved by Gallup's ethics committee and relevant governing bodies as required in each country prior to data collection. All participants provided verbal informed consent, and all local laws and restrictions were followed by Gallup while conducting interviews with 15–17-year-olds, including obtaining parental consent where required. No compensation was provided. The Gallup World Poll included local in-country researchers and study staff throughout the research process, including in the survey design and implementation.

Study sample

Data about anticipated harm were drawn from the publicly available Lloyd's Register Foundation World Risk Poll, which was funded by the Lloyd's Register Foundation and implemented in 2019 by Gallup. A full methodology report describing how surveys were developed and implemented is available from the Lloyd's Register Foundation[67]. Briefly, a national probability-based sample of ~1000 non-institutionalized individuals (i.e., those not in living in institutions such as prisons or nursing homes) aged 15 years and older in each of 142 countries were surveyed by phone or face-to-face. Simple random sampling was used in countries where Gallup conducted phone surveys. A multi-stage sampling procedure was used in countries where Gallup conducted face-to-face interviews, with stratification of administrative units to determine primary sampling units and implementation of a random-route procedure within these units. 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. Ultimately, 154,195 participants ($n = 82{,}568$ women, 71,627 men) were recruited, consented, and interviewed by trained study staff. Due to their relative population sizes, samples were larger in some countries, such as China ($N = 3709$ individuals) and India ($N = 3377$ individuals), and smaller in others, such as Jamaica ($N = 501$ individuals). Data on self-reported anticipated harm from drinking water were unavailable for Kuwait.

Data collection

Phone surveys were conducted via mobile and landline phones using sample frames purchased from vendors in countries where telephone coverage was at-least 80% or where phone interviews were customary. Otherwise, face-to-face interviews were used. As such, individuals without access to a landline or mobile phone may have been under-represented, but they comprise a small percentage of the population in most countries in which surveys were done using telephone. To address potential under-coverage and increase representativeness, Gallup applied post-stratification sampling weights. Full details on response rates, ranging from 6% in Northern America to 80% in Central and Western Africa, are available in the methodology report[67]. A prior study using these data found no evidence that face-to-face interviews and phone interviews yield differential findings[68]. Interview mode was not adjusted for because it only varied in upper middle-income countries and high-income countries, and was therefore confounded by country income category.

Gallup implemented numerous quality assurance strategies to measure perceived risks and related constructs in the most reliable, valid, and equivalent way[67,69]. First, cognitive interviews and pilot tests were used to ensure that survey topics and wording made sense to and were understood equivalently among target participants[69]. Second, consistency across languages was achieved through one of two translation strategies: two independent translations occurred and harmonized by a third party, or the document was translated by one contractor, back-translated by another, and then edited by a third. Third, each survey included a definition of risk that was read aloud to participants for shared understanding: "Risk refers to something that may be dangerous or that could cause harm or the loss of something. Risk could also result in a reward or something good." Fourth, Gallup used best data collection practices, including the development of standardized survey guides and multi-day training for interviewers, to ensure high implementation fidelity and comparability across applications. Fifth, to ensure that responses were reliably recorded, at-least 30% of surveys conducted face-to-face (through accompanied interviews or re-contacts) and 15% of those conducted via telephone (by listening to live or recorded interviews) were assessed for accuracy[67]. Sixth, to reduce the potential for psychological priming, individuals were first asked to report how worried they were about experiencing harm from each risk, then rated how likely they would experience harm from each factor in the next two years, and concluded by reporting whether they experienced harm from each factor in the prior two years. Test-retest reliability was not evaluated, such that the consistency and reproducibility of results is not known.

Experienced and anticipated harm

Self-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). Self-reported 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" because few individuals affirmed "very likely" in some countries (less than 5% in 21 countries) (Supplementary Data 2). Further, collapsing categories can improve cross-country comparability given known cultural variations in the affirmation of extreme categories (e.g., "very likely") for questions with Likert-type response formats[70].

The term "serious harm" was kept intentionally broad to account for the diverse ways by which suboptimal drinking water can manifest and in turn differentially impact well-being. Subjective interpretation of "serious harm" is central to this analysis given that idiosyncratic perceptions of risk ultimately influence behavior. The phrase was not identified as being poorly or even differentially understood in cognitive interviews or the pilot tests conducted in low-, middle-, and high-income countries[67,69].

Perceived anticipated harm from drinking water in the next two years was selected as the outcome of interest given our study aims and shortcomings in the other water-related item included in the World Risk Poll. Along with reporting likelihood of serious harm from drinking water in the next two years, individuals were asked to share "how worried are you that the water you drink could cause you serious harm?". While this item provides interesting insights into perceptions of water hazards, it does not comprehensively capture individuals' assessments of whether such risks are likely to produce harm. In some contexts, there may be other risks that pose greater threats to well-being or water issues may be normalized due to their frequency and pervasiveness, such that individuals believe they are likely to be harmed by their water but not worry it.

A single item was used for self-reported anticipated harm from drinking water to reduce survey costs and respondent burden. Single-item measures of risk perception are often highly correlated with multi-item measures of risk, showing comparable validity in terms of correlations with relevant outcomes[71]. Reliability of our single-item measure of self-reported anticipated harm is demonstrated through positive correlations with a yes/no question that asked about whether participants worried that their drinking water could cause them harm, both in aggregate ($r = 0.59$) and across countries (r: 0.17–0.83). In addition, in a generalized linear model with a binomial distribution, identity link function, and country membership included as a fixed effect, the prevalence of self-reported anticipated from drinking water was estimated to be 57.2 percentage points higher (95% CI: 55.9pp, 58.5pp; $p < 0.001$) among individuals who reported worrying about drinking water compared to those who did not, suggesting item reliability.

Country-level variables

To explore whether risk perceptions were associated with more commonly used water indicators, we leveraged other publicly available datasets. Estimates of national renewable freshwater resources (m^3 per capita, log transformed to reduce skewness) 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. Data were available for 136 of the 141 countries in the World Risk Poll with data on self-reported anticipated harm[72]. We used nationally representative data about the percentage of households in each country with at-least basic drinking water service levels (data for access to safely managed drinking water services were only available for 96 of the 141 countries), estimated by the WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation for 2019, as a proxy for water quality and access ($N = 135/141$ countries)[4].

Objective water quality data sufficient for generating cross-culturally comparable estimates of the percentage of the population using contaminated drinking water were collected in 29 countries between 2012 and 2019[19]. For this, contamination was measured by the presence of *Escherichia coli* at the point of use; *Escherichia coli* is an organism indicative of pathogenic water contamination that can cause diarrheal disease[40]. Twenty-three of these countries were in the World Risk Poll.

A publicly available dataset on wastewater production and use was used to estimate the percentage of wastewater from domestic and manufacturing processes that was treated in 2015 ($N = 137/141$ countries)[73]. The percentage of deaths in a country attributable to unsafe water was estimated using data from the 2019 Global Burden of Disease Study ($N = 138/141$ countries)[74]. Estimates of per capita GDP in 2019 (USD, log transformed to reduce skewness) ($N = 137/141$ countries), as well as classifications of country income levels (low, lower middle, upper middle, and high) ($N = 141/141$ countries), were retrieved from the World Bank database[75]. In addition, the 2019 Corruption Perceptions Index was used to estimate the perceived level of corruption in the public sector by key stakeholders, including business and political experts, within each country. The Corruption Perceptions Index is calculated by aggregating and averaging data from 13 sources (e.g., the African Development Bank Country Policy and Institutional Assessment, World Economic Forum Executive Opinion Survey), with potential scores ranging from 0 to 100; 0 represents the highest level of perceived corruption and 100 represents the lowest level of perceived corruption. Corruption Perceptions Index scores are only assigned to countries or territories with assessments from 3 or more sources ($N = 140/141$ countries)[41]. Finally, the percentage of the population that reported experiencing serious harm from drinking water in the prior two years was estimated using data from the 2019 Lloyd's Register Foundation World Risk Poll ($N = 141/141$ countries)[76].

Individual-level variables

We explored how self-reported anticipated harm varied by individual-level demographic characteristics to identify populations that are disproportionately impacted by this negative experience. Demographic characteristics included gender (determined by the interviewer as man or woman), ability to get by on present income (dichotomous: "finding it difficult" or "getting by on present income"), household location (dichotomous: "rural area, small town, or village" or "large city or suburb of a large city"), and education (categorical: ≤8 years or basic education, 9–15 years of education, completed four years of education beyond high school).

Statistical analysis

Base sampling weights for each country were developed by Gallup to account for the probability of being selected into the sample. Base sampling weights were then adjusted for non-response as well as national distributions of gender, age, and (if reliable data were available) education and socioeconomic status. First, to assess the prevalence of self-reported harm from drinking water and concern about it, we applied these post-stratification weights to generate nationally representative estimates of self-reported experienced and anticipated harm within each country. When pooling across sites for regional and aggregate estimates, we applied projection weights that accounted for each country's adult population size.

Second, to evaluate country-level predictors that explained variation in the national prevalence of self-reported anticipated harm from drinking water, we visualized trends between estimates of self-reported anticipated drinking water harm and country-level covariates using lowess curves to qualitatively assess their relationships. We then fitted weighted least squares regressions (observations weighted by the inverse of the standard errors of the dependent variable estimates for each country) with robust standard errors—which account for uncertainty in the estimated outcome, design effects, and heteroskedasticity[77]—to assess the relationship between the percentage of the population reporting anticipated harm from drinking water and predictors of interest, exploring linear and quadratic functional forms of each country-level covariate, except for percentage of deaths in a country attributable to unsafe water. The lowess curve for this variable in relation to the prevalence of self-reported anticipated harm from drinking water substantially changed at 1% of deaths attributable to unsafe water. As such, we dichotomized the variable to reflect less than ($n = 90$ countries) or greater than or equal to 1% of deaths attributable to unsafe water ($n = 48$ countries). The Akaike information criterion (AIC) was used to determine which variable form provided better model fit; lower AIC values indicate better fit (Supplementary Table 7). A multivariable model with all country-level covariates was developed to identify the most salient predictors of self-reported anticipated harm. Models met statistical assumptions, except the one with per capita renewable freshwater resources as the main predictor, which had non-normally distributed residuals.

Third, to identify which individuals are most likely to perceive their water to be unsafe, we built generalized linear models with binomial distributions and used the identity link function to estimate the prevalence difference in self-reported anticipated harm from drinking water by demographic characteristics (gender, education, household location, and difficulty getting by on present income). Each demographic characteristic was interacted with World Bank country income classification to assess for potential effect measure modification. Analyses were then stratified by World Bank country income classification given statistically significant interactions. To identify the most salient predictors of self-reported anticipated harm from drinking water, we included all demographic characteristics in a multivariable model. To account for clustering of observations within each country, we used a fixed effects approach (i.e., country membership was included as a predictor in each model); model assumptions of independence were thus satisfied.

As a sensitivity analysis, we developed a multilevel mixed effects logistic regression to understand how individual- and country-level factors may concurrently influence perceptions of potential harm from drinking water. Country membership was treated as a random effect and all other predictors were treated as fixed.

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

Reporting summary
Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability
The datasets used for these analyses are publicly available. They include data on perceived water risks from the Lloyd's Register Foundation World Risk Poll (https://wrp.lrfoundation.org.uk/data-resources/)[76], data on water availability from AQUASTAT[72], data on household drinking water services from the Joint Monitoring Programme for Water Supply (https://washdata.org/data/household#!/)[4], data on water quality from UNICEF and WHO[73], data on wastewater from Pangea (https://doi.org/10.1594/PANGAEA.918731)[73], data on deaths attributable to unsafe water from the Global Burden of Disease Study (http://ghdx.healthdata.org/gbd-2019)[74], country income data from the World Bank (https://data.worldbank.org/)[75], and data on perceived public sector corruption from Transparency International (https://www.transparency.org/en/cpi/2019/index/nzl)[41].

Code availability
Analytic code is available through an open-access repository (https://doi.org/10.21985/n2-0n23-hn72)[78].

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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. C.S., A.S., J.B.L., and W.B.d.B. contributed to data interpretation and provided substantive revisions on subsequent versions of the manuscript. All authors approved the final version.

Competing interests

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 competing interests.

Additional information

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