



Water scarcity, diarrhea, and health insurance uptake in Ethiopia: an instrumental variables approach

Bahre Gebru^{1,2,3} · Katarina Elofsson^{3,4,5}

Received: 21 April 2025 / Accepted: 3 February 2026 / Published online: 25 March 2026
© The Author(s) 2026

Abstract

Provision of safe drinking water continues to be a challenge in water-stressed African regions. This paper investigates how water scarcity affects diarrheal illness and health insurance uptake in Ethiopia. It further examines heterogeneous effects related to households' water purification habits and handwashing facilities, and identifies underlying mechanisms. The study combines socioeconomic data with high-resolution weather and water quality test data. The analysis uses an instrumental variables approach with temperature shocks as an instrument for water scarcity. Findings indicate that a 1% rise in water scarcity is associated with an increased probability of diarrheal illness by 4.2% and acquisition of health insurance by 2.5%. The impact on diarrheal illness is larger among households that do not boil their water and lack access to handwashing facilities with water. No significant difference in health insurance ownership is observed between households that purify drinking water and those that do not. This result potentially reflects higher risk aversion among the former. The effects are driven by households' use of unimproved water and sanitation facilities as well as higher medical spending on doctor visits and prescribed medications. These results highlight the need to improve water access and expand health insurance to reduce climate-related health risks in Ethiopia.

Keywords Diarrheal illness · Ethiopia · Health insurance · Instrumental variables · Water scarcity

Introduction

Access to safe drinking water is a basic necessity with no real substitute (Innes and Cory 2001; Damania et al. 2020; Hope et al. 2020). However, concerns about water scarcity are growing globally (Debaere and Kapral 2021; He et

al. 2021; Olley et al. 2024). By 2050, it is projected that approximately two billion people will experience severe water scarcity (Onyena and Sam 2025). Climate change is intensifying water scarcity through greater unpredictability and volatility in water supplies (Gosling and Arnell 2016; Russ 2020; Deghani et al. 2024). Climate-driven changes in water availability increase time and effort households spend collecting water (Carr et al. 2024; Paulos et al. 2025) and exacerbate exposure to unsafe water sources.

The use of unsafe water sources could lead to serious health consequences (Hope et al. 2020), including diarrheal illness, adverse birth outcomes (Rocha and Soares 2015), and infant mortality rates (IMR) (Gamper-Rabindran et al. 2010). The World Health Organization (WHO) reports that diarrheal illness affects over 1.7 billion children globally each year. It is the third leading cause of death among under-five children, causing roughly 444,000 deaths each year (WHO 2024). Due to the impact on health risks, water scarcity can push households to acquire health insurance, particularly in vulnerable, water-stressed areas. This could lower the risk for high, out-of-pocket healthcare costs (Galárraga et al. 2010; Zhang et al. 2017) related to doctor

✉ Bahre Gebru
bahre.kiros@statsvet.uu.se

Katarina Elofsson
katarina.elofsson@envs.au.dk

¹ Department of Government, Uppsala University,
75120 Uppsala, Sweden

² Centre of Natural Hazards and Disaster Science (CNDS),
Uppsala University, Uppsala, Sweden

³ Department of Economics, Swedish University of
Agricultural Sciences, Uppsala, Sweden

⁴ Department of Environmental Science, Aarhus University,
4000 Roskilde, Denmark

⁵ Department of Social Sciences, Södertörn University,
Huddinge, Sweden

visits, prescribed medications, and diagnostic tests. However, despite expanded pooled and prepaid financing, many people still face health expenditures causing severe financial burden (World Bank 2023). However, the quantitative links among water scarcity, diarrheal illness, and the acquisition of health insurance are not well known.

Access to safe drinking water and sanitation is a key predictor of diarrheal illness (Mebrahtom et al. 2022; Chen et al. 2023; Merid et al. 2023; Mappingure et al. 2024). However, prior studies on diarrheal illness have several limitations. First, these studies tend to rely on binary measures of water and sanitation quality, overlooking the role of time spent collecting water. Second, most analyses provide a limited understanding of the temporal dynamics of decisions on water and sanitation due to the use of cross-sectional data (Gaffan et al. 2023; Abera et al. 2024). Third, studies neglect older children and adults, focusing primarily on illness among under-five children (Mebrahtom et al. 2022; Chen et al. 2023; Merid et al. 2023). Fourth, many studies are constrained to specific regions within countries, reducing the generalizability of results (Onohuean and Nwodo 2023; Pessoa Colombo et al. 2023). Moreover, past research has also documented the effects of climate change on both water scarcity (Gosling et al. 2016; Dehghani et al. 2024; Kåresdotter et al. 2025) and the uptake of crop insurance as an adaptation measure (Aina et al. 2024; Abrego-Pérez et al. 2025). However, it remains unclear whether climate change-driven water scarcity affects household decisions to adopt health insurance as an adaptation measure to increased health risks.

The purpose of this paper is to analyze the role of water scarcity in health outcomes in Ethiopia. Specifically, it seeks to (1) investigate how water scarcity affects the risk of diarrheal illness and health insurance uptake, (2) examine how the effects differ depending on household water purification practices and the presence of handwashing facilities, and (3) identify the underlying mechanisms. Following past research (Loughran and Pritchett 1997; Cooke 1998; Nankhuni and Findeis 2004), this study defines water scarcity as the daily water collection time per household. Scarcity can result from insufficient supply or poor quality (Belhassan 2021). As water scarcity increases, households spend more time collecting water, which raises the shadow price of the water resource and tends to decrease the consumption of improved water. Inadequate access to improved water directly threatens health, contributing to water, sanitation, and hygiene-related problems, as well as diarrheal illness (Boone et al. 2011; Usman et al. 2019). The focus on Ethiopia in this study is motivated by the high incidence of diarrheal illness (Asgedom et al. 2023; Motuma et al. 2025), significant household time spent collecting water (Central Statistics Agency of Ethiopia and World Bank 2017; Mosa

et al. 2020), and vulnerability to climate-related water scarcity (Edamo et al. 2022; Gebru et al. 2025).

The analysis makes use of data from the Living Standard Measurement Study-Integrated Surveys on Agriculture (LSMS-ISA) for Ethiopia. It is a large-scale, nationally representative data collected during 2013/14 and 2015/16. This dataset is supplemented with weather data from the University of East Anglia's Climatic Research Unit and Water Quality Test (WQT) data from LSMS-ISA, collected in 2015/16. Using high spatial resolution rainfall and temperature data, yearly temperature and rainfall shocks are constructed. The analysis then applies an instrumental variables approach by exploiting variations in temperature shocks as an instrument for water scarcity. In addition, it makes use of microbiological and chemical WQT data to support the validity of the exclusion restriction.

Results show that a 1% increase in water scarcity raises the likelihood of diarrheal illness by about 4.2% (in both adults and children under-seven) and increases health insurance acquisition by 2.5%. These effects are observed in both households lacking water purification habits and those without access to handwashing facilities. The scarcity impacts health outcomes by necessitating the use of unimproved water and sanitation facilities, and by raising out-of-pocket medical spending.

The paper makes three contributions to research on the relationship between water services and health outcomes. First, the study enhances statistical reliability and generalizability of existing findings (Chankrajang 2019) on diarrheal illness by using nationally representative individual- and household-level panel data. The data used allows for performing multiple robustness and validity tests (cf. e.g., Usman et al. 2019) that enhance the credibility of the results. For example, by comparing how water scarcity affects households differently, the analysis adds to the relatively scarce research on the role of water purification (Boelee et al. 2019; Raimann et al. 2020) and handwashing (Freeman et al. 2014) in preventing diarrheal illness. Second, research has predominantly focused on children under five although diarrheal illness affects all age groups (Srivastava et al. 2022; Zhao et al. 2025). The current study extends this literature by analyzing the effect of water scarcity on both adults and under-seven children. This approach accounts for household spillover effects, acknowledging that illness of one household member can influence the health outcomes of other members. Finally, this paper presents new evidence on existing adaptation strategies to water scarcity (Singh et al. 2018; Achore et al. 2020; Mapuka et al. 2024) by documenting that households adopt health insurance to reduce medical costs.

Context and conceptual framework

Context

Water, sanitation, and hygiene (WASH) in Ethiopia

The World Bank, African Development Bank, United Nations Children's Fund (UNICEF), and WHO assessed progress in water supply and sanitation across Sub-Saharan Africa. The analysis identified bottlenecks in service delivery and prioritized actions to turn finance into effective water and sanitation services. This has helped Ethiopia strengthen spare-part availability in rural water supply chains and enhance financial autonomy of town utilities. It has also introduced cost recovery approaches (UNICEF 2015). This may have contributed to expanding water supply access in the country. Access to improved drinking water rose from 70% in 2019 to 74% in 2022. Urban areas like Addis Ababa, Dire Dawa, and Harari have better access. Somali (48%), Afar (58%), and Amhara (73%) lag behind. Rural access grew from 62 to 69% over the same period. Access to piped water reached 43% in 2022 (Central Statistics Agency of Ethiopia and World Bank 2023). Yet, about 31% of Ethiopians use unimproved drinking water, with regional variations (Aragaw et al. 2023).

Despite recent progress, Ethiopia falls behind the global average. It is ranked 112th of 117 countries in improved water supply, 95th out of 96 in improved sanitation facility, and 71st of 78 in handwashing with soap (UNICEF and WHO 2019). Access to improved sanitation is still limited. A recent report indicates that only 26% of Ethiopians had improved sanitation facilities during 2022. The availability of basic hygiene services, such as households with handwashing stations equipped with soap and water, remains low (Central Statistics Agency of Ethiopia and World Bank 2023). The limited access to safe water and sanitation could have serious health implications. Ethiopia is ranked among the top five countries for under-five pneumonia and diarrheal deaths (International Vaccine Access Center 2020). The poor water infrastructure and unimproved water sources could contribute to diarrheal illness.

This paper adopts the commonly used improved/unimproved classification of facility types suggested by Girma et al. (2024). Access to piped water, boreholes, protected wells and springs, and packaged or delivered water is classified as having “improved” drinking water. In contrast, water from unprotected wells, springs, or surface sources (e.g., rivers, lakes, and ponds) is considered “unimproved.” Improved sanitation facilities include flush toilets, ventilated improved pit latrines, pit latrines with slabs, and composting toilets. Unimproved facilities, however, consist of pit latrines without slabs, bucket latrines, open defecation in natural

areas, and waste disposal alongside solid waste. Unlike the unimproved sanitation facilities, improved facilities ensure hygienic separation of human waste from contact.

Health insurance in Ethiopia

In Ethiopia, the health sector faced critical challenges, leaving many households struggling to access healthcare until 1998. Policy decisions often favored hospitals and urban areas. Insurance coverage was minimal or non-existent, and private sector participation was limited. To address this, the Council of Ministers introduced the supply-side Health Care Financing Strategy in 1998. This strategy aimed to mobilize resources, prioritize primary care, and promote community involvement and ownership in health services (Ethiopian Health Insurance Agency 2015). There were also reforms targeting the insurance sector, including the Social Health Insurance Scheme (SHIS) and the Community-Based Health Insurance Scheme (CBHIS). These initiatives were intended to pool risks and shield households from excessive out-of-pocket health expenditures. While SHIS provides financial protection for the formal sector, CBHIS focuses on individuals working in rural and informal sectors.

CBHIS was launched as a pilot in 2010/11. It initially covers 13 districts across four major regions: 4 in Oromia, 3 in Amhara, 3 in Tigray, and 3 in the Southern Nations, Nationalities and People (SNNPR) region. After a three-year pilot phase, the scheme underwent implementation in approximately 161 districts. The scheme has been further expanded to 827 districts by 2020 (Ethiopian Health Insurance Agency 2020). It is voluntary, requiring households to pay monthly premiums based on their composition. For parents and their children under 18, premiums per household are between Ethiopian Birr (ETB) 10.50 in SNNPR to ETB 15 in Oromia. Other household members contribute about ETB 2.10–3 per month. However, each individual pays ETB 3 per month in Amhara (Mebratie et al. 2019) as regions can adjust premiums according to their local context. Premiums average 0.5% of household income. Governments (district and regional) cover waivers for the poorest 10%. About 7.4% of eligible households had a fee waiver by December 2013. Local officials and communities identify and implement the waivers (Ethiopian Health Insurance Agency 2015).

The scheme covers all care in Ethiopian public facilities. Private treatment is only funded if a service is not available publicly. CBHIS members avoid co-payments if they follow referrals, starting at a health center before moving to higher hospitals. CBHIS enrollment increases outpatient use by 30–41% and visit frequency by 45–64%. It also cuts the cost per visit by at least 56%. With nearly 50% uptake in two years since its inception, the Ethiopian scheme has

shown strong success (Mebratie et al. 2019). However, there is a fear that the flat-rate premium could lead low-income households to delay or skip enrollment (Wassie et al. 2023; Birhanu et al. 2025).

Conceptual framework

Improving access to safe drinking water and sanitation facilities reduces diarrheal illness and aligns with the Sustainable Development Goals (Pullan et al. 2014; Fotio and Nguea 2022). However, water scarcity could challenge health outcomes. Ethiopia has one of the world's poorest drinking water infrastructures (Aragaw et al. 2023). Disruptions in access to improved water supply often force households to gather water from unprotected sources (Chalchisa et al. 2017; Gebremichael et al. 2021). Such practices can have serious health impacts, and are argued to contribute to around 50% of global diarrheal deaths (Adamu and Ndi 2018; Aragaw et al. 2023). Sanitation facilities alone are not sufficient to ensure health improvements. A steady water supply is critical for proper hygiene, as water is essential for flushing and cleaning. When water access is unreliable, people are more likely to use unimproved sanitation facilities, such as open defecation (Dickinson et al. 2015; Coffey et al. 2017; Cameron et al. 2019), where it is difficult to maintain hygiene (Saxton et al. 2017). Hence, without adequate water access, people are likely to avoid water-dependent sanitation facilities like flush toilets. This leads to sanitation and health problems (Spears 2020).

Climate change increases the number of hospital visits (White 2017), hospitalizations and mortality (Karlsson and Ziebarth 2018; Agarwal et al. 2021), and leads to higher medical spending (Li et al. 2023). When households depend on unimproved water and sanitation facilities that are vulnerable to climate change, the risk of diarrheal illness increases, contributing to these adverse health outcomes. These outcomes are associated with a household risk for high medical spending, which could motivate the purchase of health insurance. Health insurance helps reduce out-of-pocket healthcare expenditures, as shown in studies from China (Zhang et al. 2017) and Mexico (Galárraga et al. 2010). In Ethiopia, involvement in CBHIS has also been shown to lower households' direct cost per healthcare visit (Mebratie et al. 2019). Thus, purchasing health insurance could enable households to manage the costs of treating diarrheal illnesses without exhausting their savings.

Materials and methods

Data and measurement of variables

This subsection describes the secondary data sources utilized in the study. It includes LSMS-ISA, weather data, and WQT data.

LSMS-ISA

LSMS-ISA for Ethiopia, a joint initiative by the Central Statistics Agency of Ethiopia and the World Bank, serves as the primary data source (Central Statistics Agency of Ethiopia and World Bank 2017). This is a large-scale, nationally representative data that has five waves gathered in 2011/12 (ESS-1), 2013/14 (ESS-2), 2015/16 (ESS-3), 2018/19 (ESS-4), and 2021/22 (ESS-5), respectively. This study utilizes ESS-2 and ESS-3, which were collected between February and April of 2014 and 2016, respectively. These waves are preferred because they include both urban and rural areas and use a 2-week diarrhea prevalence recall window. This short recall window minimizes reporting errors (Bandyopadhyay et al. 2012). The 4-week disease prevalence window in ESS-3 is also utilized for falsification testing. Earlier and later waves are excluded because of insufficient data. First, ESS-1 covers only rural areas and has a two-month disease recall period, risking reporting error. Second, ESS-4 and ESS-5 are not direct follow-ups to earlier waves and therefore cannot be linked to form a joint panel with ESS-2 and ESS-3.

Third, ESS-5 excludes the Tigray region (covered in ESS-4) due to war (Central Statistics Agency of Ethiopia and World Bank 2023), precluding a balanced panel even across the final two waves. Fourth, ESS-3 contains the WQT data (described in detail below). This data is the only publicly accessible source of water quality information that can be combined with LSMS-ISA socioeconomic data. ESS-3 is essential for testing potential violations of the exclusion restriction, making ESS-4 and ESS-5 empirically irrelevant. Results from ESS-4 and ESS-5 are included in Table S8 for completeness and largely corroborate the main findings. These findings address neither endogeneity nor the exclusion restriction and are therefore excluded from the main results. The dependent variables are whether [NAME] (a) experienced diarrhea in the past two weeks (1 yes, 0 no), and (b) currently has health insurance: employer-based, community-based, or private (1 yes, 0 no). Diarrheal illness is analyzed using pooled panel data from both waves, while health insurance is examined with data only from ESS-3, as ESS-2 does not include this information.

ESS-2 and ESS-3 contain about 3776 and 3699 households, respectively. The respondents in these waves are

distributed across all regions, including the cities of Addis Ababa and Dire Dawa. Samples are also gathered from households in all medium-sized and large town Enumeration Areas (EAs). Following a two-stage clustered sampling approach, EAs and households in the EAs are selected in the first and second stages, respectively. Households are randomly selected. Figure 1 shows the distribution of sample households across regions.

The concept of collection time has previously been applied in several studies to examine consequences of resource scarcity. Examples include the impact of firewood and water scarcity on child demand in Nepal (Loughran et al. 1997), children's school attendance in Malawi (Nankhuni et al. 2004), and the effects of fuelwood, leaf fodder, and cut grass scarcity on intrahousehold labor allocation in Nepal (Cooke 1998). The current paper adopts this approach, treating time spent collecting water as an opportunity-cost proxy for water scarcity. From the ESS household questionnaire, water scarcity is measured by asking a household head, "How many hours did [each household member] spend collecting water the day before the survey?" Households'

total water collection time equals the sum of hours for all members.

Other socioeconomic factors considered include the household head's gender, age, and level of education (uneducated, primary, secondary, certificate, and tertiary), as well as the duration of breastfeeding and exclusive breastfeeding in months since birth for children under-seven. The analysis also contains an indicator for wealth. Nominal household consumption expenditure is first calculated as the annual sum of expenditure on food, non-food, and education. The corresponding real consumption expenditure is obtained by dividing nominal expenditure by regional price indices to account for price variations across space and time. The ratio of real household consumption expenditure to adult equivalent serves as a proxy for wealth. This proxy accounts for economies of scale in consumption, and follows the approach in Nelson (1988) and Alem et al. (2016). The wealth variable is winsorized at 1% and 99% levels to limit outliers and then transformed to its natural logarithm. Because households may adjust their water storage in response to a changing climate (Fisher and Rubio 1997),

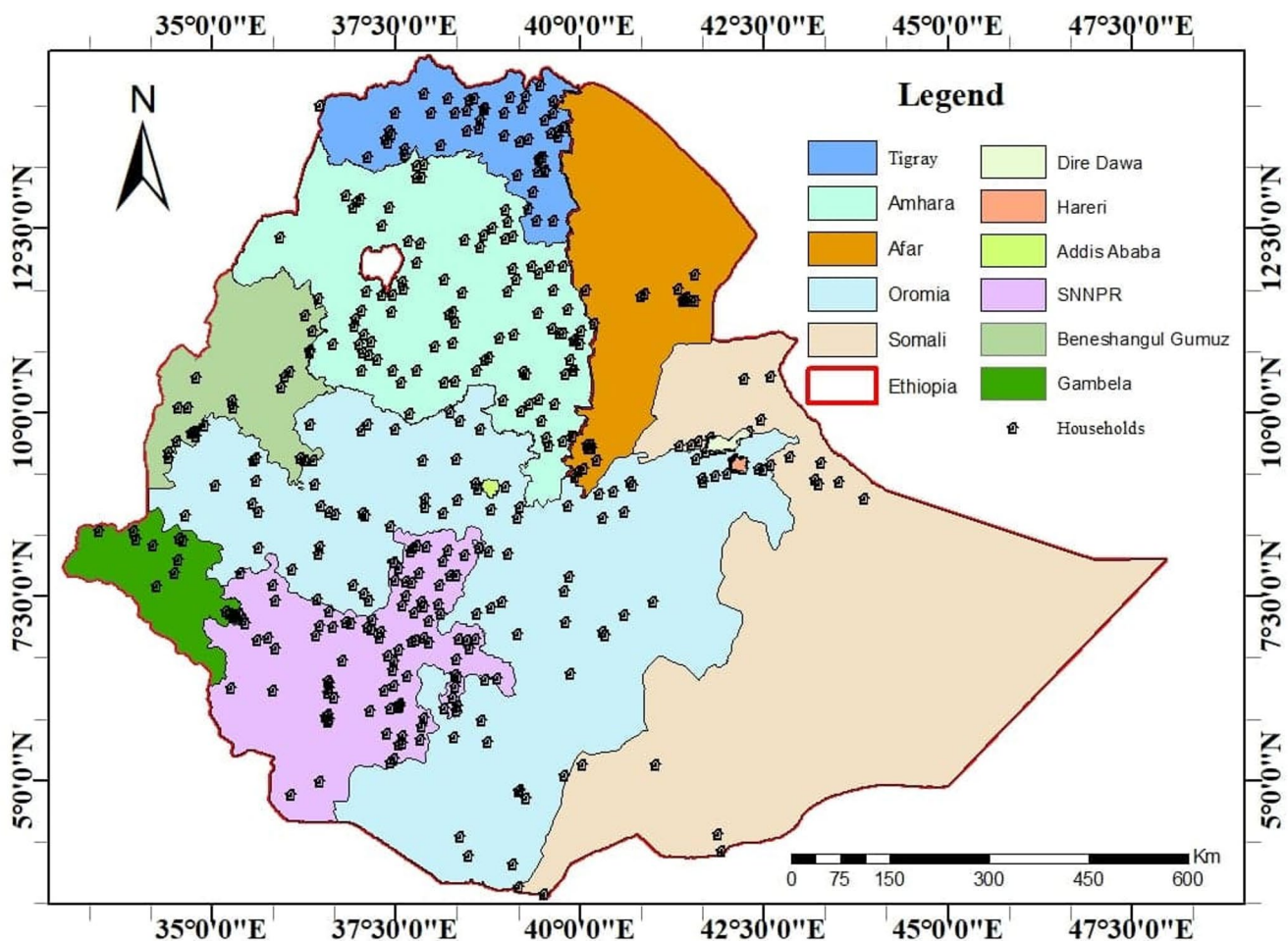


Fig.1 Geographic locations of households based on ESS

the analysis uses share of water-related spending (e.g., purchases of water tanks) as an indicator of adaptation to rainfall shocks.

The analysis explores three ways in which water scarcity affects health outcomes. The first two relate to a household's use of improved or unimproved water and sanitation facilities, as outlined earlier. The third mechanism is an individual's yearly medical spending in ETB. Based on the LSMS-ISA household questionnaire, this variable reflects the cost of medical consultation, including prescribed medications or tests, regardless of where they were obtained. The amount is zero if there are no such expenses.

Weather data

The LSMS-ISA provides latitude and longitude coordinates for surveyed households. The authors use these geocoordinates with ArcGIS to extract historical weather data from the University of East Anglia's Climatic Research Unit and construct annual rainfall and temperature shocks. The Research Unit provides monthly records of minimum and maximum temperatures (°C) and precipitation (mm) at a spatial resolution of about 1 km². The annual average temperature is calculated by adding the minimum and maximum temperatures and dividing the result by two.

The authors measure weather shocks in terms of log deviations of average rainfall and temperature values from their current annual values for the same household. The log is only defined for positive values. Given that temperature and precipitation levels exceed historical averages in the data, the logged values are always positive. The past 30 years relevant to each survey wave (i.e., 1983–2012 for ESS-2 and 1985–2014 for ESS-3) are used to calculate historical means. This approach omits the data collection periods of 2013/14 and 2015/16 and ensures that past weather values are exogenous to current shocks (Dercon and Christiaensen 2011). More specifically,

$$Shock_{wht} = \ln \left(\frac{X_{wht} - \bar{X}_{wht-1}}{\bar{X}^{SD}_{wht-1}} \right) \quad (1)$$

where $Shock_{wht}$ represents a weather shock for a weather variable w at location of household h in time t , measured in standard deviations. The expression X_{wht} is the current value of each weather variable and \bar{X}_{wht-1} is the historical average for each weather variable for the nearest preceding three decades. The term \bar{X}^{SD}_{wht-1} is the standard deviation of historical weather values for each weather variable. Higher temperatures increase evapotranspiration, reduce water availability, and increase household water collection burdens (Ajjur and Al-Ghamdi 2021; Carr et al. 2024; La Fuente et al. 2024). According to Eq. (1), a

positive temperature shock, defined as the current temperature being higher than the 30-year average, worsens water scarcity. However, under positive precipitation shocks, water scarcity becomes less severe (Paulos et al. 2025). The LSMS-ISA and weather data are linked using individual and household identification numbers as well as geo-coordinates for the main analysis.

WQT data

The WQT data contains information on water quality, based on samples taken from households and water sources, targeting households included in ESS-3 (Central Statistics Agency of Ethiopia and World Bank 2017). Their fieldwork occurred during May to July 2016. This dataset is the only publicly accessible source that can be integrated with the LSMS-ISA data. Water quality is a critical confounder in the relationship between water scarcity and health outcomes. ESS-3, unlike the other waves, provides a clear advantage in assessing potential violations of the exclusion restriction using WQT data. The risk of *Escherichia coli* (*E. coli*), which increases the risk of diarrheal illness, is assessed using microbiological data. This study follows the report by Central Statistics Agency of Ethiopia and World Bank (2017) to construct *E. coli* concentrations into three risk categories: low, moderate, and high.

Chemical data on fluoride content, water hardness, and electroconductivity is also provided in the same survey. Fluoride content in drinking water should not exceed 1.5 mg per liter (mg/L) per WHO guideline. The national threshold for water hardness is 300 mg/L of CaCO₃, calcium carbonate (WHO 2011). With no Ethiopian or WHO guideline, electroconductivity is evaluated using an Australian standard of below 800 microsiemen per centimetre to indicate satisfactory water quality (Radcliffe 2018). After combining ESS-3 and WQT data using individual and household identification numbers as well as geo-coordinates, the WQT indicators are used to test for potential threats to instrument validity.

Empirical methods

The authors estimate the relationship between water scarcity and health outcomes using the following model:

$$Y_{iht} = \theta Scarcity_{ht} + \gamma Z'_{iht} + \pi X'_{ht} + \tau_v + \tau_y + \epsilon_{iht}, \quad (2)$$

where Y_{iht} is the health outcome (probability of diarrheal illness and purchasing health insurance) for individual i in household h in year t . $Scarcity_{ht}$ denotes household water scarcity, measured as total hours spent collecting water the day before the survey. The coefficient of interest is θ . The vector Z'_{iht} refers to diarrheal illness prevention measures

for children under-seven. These controls are included because the rate of diarrhea mortality increases 8 to ten-fold when parents fail to initiate breastfeeding (Yoon et al. 1996). The vector indicates the number of months a child has been breastfed and exclusively breastfed since birth. The associated coefficient vector is γ . The vector X'_{iht} contains other individual and household-level characteristics, such as gender and wealth, with π as the associated coefficient. The variables τ_v and τ_y (with τ_y used only in the diarrheal illness model) represent the village fixed effects and year fixed effects, respectively. Water sources during rainy season (e.g., water taps, water from stores, protected wells, unprotected wells, etc.) are further controlled for robustness checks. The term ε_{iht} is an error term.

The outcome variables in Eq. (2) are binary and could thus be modeled using probit models. However, the linear probability model (LPM) is used in estimating the equation because it offers a prime advantage in terms of reporting the weak instrument test statistic. This model is preferred to its counter parts in approximating response probability in binary response models (Wooldridge 2010; Couttenier and Soubeyran 2013). However, LPM is also criticized for heteroskedasticity and producing probabilities outside the [0, 1] range (Horrace and Oaxaca 2006). Results are robust to nonlinear probit estimators (Table S5 in the Supplementary Information).

Estimation of Eq. (2) begins with ordinary least squares (OLS). However, *Scarcity* is suspected to be endogenous. The effect of water scarcity on θ could thus be biased. One source of endogeneity is that households' water collection time depends on observable factors (e.g., availability of alternative water sources), unobservable factors (e.g., purpose of water fetching, such as drinking, sanitation, livestock feeding, etc.), preferences, and perceived water quality. These factors influence water scarcity while also potentially affecting health outcomes, creating a correlation between the explanatory variable and the error term.

This study attempts to minimize the endogeneity concern by using an instrumental variable, two-stage least squares (IV/2SLS) estimation approach. The technique exploits variations in historical temperature shocks as an instrument for water scarcity. The first-stage and second-stage equations (Wooldridge 2010) become:

$$\begin{aligned} Scarcity_{ht} = & \beta_1 Shock_{temp,ht} + \beta_2 Shock_{rain,ht} \\ & + \rho Z'_{iht} + \varphi X'_{ht} + \tau_v + \tau_y + \varepsilon_{iht} \end{aligned} \quad (3)$$

and

$$\begin{aligned} Y_{iht} = & \theta_S \widehat{Scarcity}_{ht} + \beta_R Shock_{rain,ht} + \gamma Z'_{iht} \\ & + \pi X'_{ht} + \tau_v + \tau_y + U_{iht}, \end{aligned} \quad (4)$$

where $\widehat{Scarcity}_{ht}$ is the predicted water scarcity from the first-stage Eq. (3). $Shock_{temp,ht}$ is the single excluded instrument, and other variables are defined as before. Conditional on the set of controls, the identifying assumption is that temperature shocks affect the health outcomes only via its effect on water scarcity. Temperature shocks are annual, while diarrheal illness spans a 2–4 week reporting period and physiological effects (e.g., heat stress and dehydration) operate over even shorter periods (Millard-Stafford et al. 2025). This temporal mismatch makes direct effects of temperature shocks on diarrheal illness and heat stress less likely. However, the direct effects of temperature shocks on health insurance could be more pronounced as insurance is typically purchased on an annual basis, so our estimates may not be strictly causal. Rainfall shocks is not a suitable instrument for water scarcity because higher rainfall (flooding) can directly affect health outcomes through its effect on agricultural production and water pollution. The analyses therefore control for the direct effect of rainfall shocks in Eq. (4).

Some variables need to be transformed into logarithms to minimize the effect of outliers. However, two variables (water scarcity and budget share of water spending) contain cases with zero values, implying that the log is undefined. The inverse hyperbolic sine transformation approach (IHSTA) solves this problem and retains the zero-value observations. For any random variable ϑ , the IHSTA becomes $\ln(\vartheta + \sqrt{\vartheta^2 + 1})$ (Burbidge et al. 1988; Bellemare and Wichman 2020)

Equation (5) is further estimated to identify the mechanisms through which water scarcity affects health outcomes:

$$Mechanism_{ht} = \beta Scarcity_{ht} + \delta X'_{ht} + \tau_v + \tau_y + \varepsilon_{ht}, \quad (5)$$

where $Mechanism_{ht}$ shows the probability of using season-specific unimproved water sources, sanitation facilities, and annual medical spending in ETB per individual per year. X'_{ht} are household-level controls, and the other variables are as introduced above.

Results and discussion

Summary statistics

Table S1 in the Supplementary Information presents summary statistics. It shows that 9.7% of individuals in the sample reported diarrheal illness in the past two weeks based on pooled panel data (column 2) and 7.8% based on 2015/16 data (column 4). However, the percentage decreases to 1% when extending the diarrheal illness observation period to the four weeks preceding the survey (column 4). This might

indicate that recall bias leads to omissions and underreporting rather than exaggeration. A typical household spends about 2 h per day on water collection. Rainfall and temperature shocks have average values of 5.6 and 4.7 standard deviations, respectively. Rainfall shocks range from a minimum of 3.6 to a maximum of 6.4 and temperature shocks range from 4.1 to 5.1. Roughly 57% of households meet the fluoride standards, 49% satisfy the water hardness standards, and 51% comply with the electroconductivity standards. About 5.3% of individuals in the data acquired health insurance in ESS-3 (column 4).

Empirical results

Water scarcity and likelihood of diarrheal illness

Table 1 illustrates the association between water scarcity and the probability of experiencing diarrheal illness. Columns 1 through 6 account for various controls, village fixed effects, and year fixed effects, based on the pooled panel data with a two-week observation window. Columns 1 and 2 report OLS estimates for the full sample and under-seven children, respectively, showing that higher water scarcity

is associated with an increased likelihood of diarrheal illness. Columns 3 and 4 portray the first-stage results for the full sample and under-seven children, respectively. The coefficients of temperature shocks indicate that a one standard deviation increase in temperature shocks results in a 13% and 27% average increase in water scarcity for the respective sample groups. These findings corroborate past research reporting temperature increases daily water collection times (Carr et al. 2024; Paulos et al. 2025). The study by Carr et al. (2024) find that each 1 °C increase in temperature corresponds to an approximate 4-min rise in daily water collection time at a global level. A 1 °C increase in temperature over a past year is also shown to be associated with an increase in water-fetching walking time of 0.76 min in Sub-Saharan Africa (Paulos et al. 2025).

The weak IV test (F-statistic) on excluded instruments is used to check the relevance of the instrument throughout the paper. The F-test results, displayed at the bottom of the regression tables, consistently exceed 10, as suggested by Staiger and Stock (1997) and Stock et al. (2002). In instances where first-stage results are omitted to conserve space, the statistical significance of the instrument at the first-stage is reported at the bottom of each regression table to verify its validity. The first-stage estimation results, conditional on the

Table 1 Water scarcity and the probability of diarrheal illness

	Pooled panel based on two-week period						Second stage: falsification tests based on four-week period			
			First-stage: water scarcity		Second-stage		Full sample		Under-seven	
	Full sample	Under-seven	Full sample	Under-seven	Full Sample	Under-seven	Physical injuries	TB	Physical injuries	TB
	OLS	OLS	OLS	OLS	IV	IV	IV	IV	IV	IV
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	10	
Temperature shocks			0.130*** (0.042)	0.271*** (0.065)						
Water scarcity (IHSTA)	0.018*** (0.006)	0.032*** (0.008)			0.410* (0.223)	0.237** (0.115)	-0.014 (0.015)	0.003 (0.006)	0.013 (0.032)	0.006 (0.013)
Observations	8,075	3,641	8,075	3,641	8,075	3,641	19,007	19,007	3,641	3,641
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No
Weak IV test statistics			22.37	13.75			70.80	70.80	13.75	13.75
IV significance at first stage			1%	1%			1%	1%	1%	1%

Note: Columns 1–2 report whether household members experienced diarrheal illness in the past two weeks for the full sample and children under-seven, respectively. Columns 3–4 are the first-stage regressions and columns 5–6 the second-stage regressions for each group. Columns 7–10 show falsification tests on non-water-borne diseases four weeks before the survey: whether household members suffered physical injuries (columns 7 and 9) and tuberculosis (TB) (columns 8 and 10). Columns 1–4 are linear probability models estimated with OLS, while columns 5 to 10 are IV/2SLS estimates. Controls include rainfall shocks, the proportion of household spending on water and water-related infrastructure per month, its interaction with rainfall shocks, rural residency, male gender, age in years, log of real household consumption expenditure (along with its square), household size, and educational levels of the household head. Columns 2, 4, 6, 9, and 10 additionally incorporate exclusive breastfeeding and duration of breastfeeding in months. The authors apply IHSTA for water scarcity and the share of household monthly water spending. Robust standard errors, clustered at the individual level, are presented in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

set of controls, show the effectiveness of the instrument for all regressions. The IV/2SLS results presented in columns 5 and 6 of Table 1 suggest that an increase in water scarcity triggers the likelihood of experiencing diarrheal illness for both the full sample and children under seven. Specifically, a 1% rise in water scarcity corresponds to a 0.41 percentage point increase in the probability of suffering from diarrheal illness for the full sample. Given that the average probability of experiencing diarrheal illness is approximately 9.7% for this sample, the result implies a 4.2% increase in diarrheal illness following a 1% rise in water scarcity. The effect remains robust in the under-seven subsample (Table 1, column 6). A 1% increase in water scarcity is linked to a 0.24 percentage point rise in the likelihood of diarrheal illness among children under seven. About 6.1% of children in the sample have reported experiencing diarrhea. This implies that a 1% increase in water scarcity raises the probability of diarrheal illness by approximately 3.9%, *ceteris paribus*. The overall impact is comparable to related results in the literature. Gamper-Rabindran et al. (2010), for example, report that a one percentage point increase in the number of households receiving piped water reduces IMR per thousand live births by 1.25 at the 90th percentile of the conditional IMR.

In addition to water scarcity, X'_{ht} , Eq. (2) includes other determinants of diarrheal illness. One key group of factors relates to social status, such as household consumption and the square thereof, the share of monthly spending on water and water-related infrastructure, education level of household head, and household size. These findings are presented in Table S2. These results indicate that larger households are less likely to report cases of diarrheal illness in the full sample. This may suggest that more household members mean shared water-collection tasks, better water availability, and reduced diarrheal illness. Nonetheless, this finding is at odds with previous studies, which report that adding an extra household member increases the risk of diarrheal illness (Abadie et al. 2022; Bah et al. 2022). Contrary to expectations, the results further show that more educated household heads appear correlated with increased diarrheal illness in under-seven children. This likely reflects the trade-off for educated household heads, where participation in income-generating activities could reduce their water collection time. Evidence from northern Ethiopia shows that children in literate-headed households spend 50% more weekly time collecting water, firewood, and fodder than those in illiterate-headed households (Gebru and Bezu 2014). This burden could trigger the risk of diarrheal disease in children, as documented by Geere and Hunter (2020), likely due to greater exposure to contaminated water sources.

Robustness checks and validity concerns on diseases reporting

Several sensitivity analyses and validity tests concerning diseases reporting are conducted to ensure the robustness of the findings. First, the paper explores whether factors associated with diarrheal illness prevention in children, such as breastfeeding duration and exclusive breastfeeding, might influence the interpretation of the results. The model incorporates these diarrheal illness prevention mechanisms into column 6 of Table 1, concluding that the effect of water scarcity remains consistent. Second, the identifying assumption that no time-varying omitted variables affect both water scarcity and diarrheal outbreaks is examined. This is meant to provide a consistent estimate of θ_S in Eq. (4). Falsification tests are undertaken to assess whether the degree of water scarcity correlates with the likelihood of non-water-borne diseases, such as physical injuries and tuberculosis (TB), using data from ESS-3. The absence of any discernible effect on non-water-borne diseases in columns 7–10 of Table 1 confirms that only diarrheal illness is driven by water scarcity. These results reduce threats to identification from omitted variables correlated with water scarcity and other health problems.

In both samples, omitted variables and strategic incentives could introduce subjective judgements when respondents report on time-bounded prevalence of diseases (Garg 2019). The analysis verifies the validity of the dependent variables on disease prevalence in two ways. Firstly, it shows that distance from household residence to nearest population center with at least 20,000 inhabitants strongly affects the prevalence of each disease type (Table S3, columns 1 and 2). These results show that remote areas in Ethiopia are more prone to water- and non-water-borne diseases. The falsification tests show that water scarcity has no effect on other diseases but diarrheal illness. If water scarcity was associated with subjectivity in disease reporting but not with distance to urban centers, one would perhaps find a significant relationship between water scarcity and at least one of the non-water-borne diseases. Secondly, the concern of strategic behavior in reporting (exaggerated) disease prevalence to attract better medical support seems not evident for this context. Columns 3 and 4 of Table S3 confirm water scarcity is not related to the likelihood of receiving any medical assistance for both the full sample and children, respectively.

Water scarcity and probability of purchasing health insurance

Table 2 portrays the relationship between water scarcity and the probability of having health insurance. All columns

Table 2 Water scarcity and probability of health insurance ownership

			First-stage: water scarcity		Second-stage	
	OLS	OLS	OLS	OLS	IV	IV
	(1)	(2)	(3)	(4)	(5)	(6)
Temperature shocks			0.377*** (0.025)	0.316*** (0.027)		
Water scarcity (IHSTA)	0.001 (0.003)	0.002 (0.003)			0.106*** (0.024)	0.133*** (0.033)
Observations	20,258	19,007	20,136	19,007	20,136	19,007
Controls	No	Yes	No	Yes	No	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes
Weak IV test statistics			62.90	70.80		

Note: The dependent variable in columns 1 and 2 is whether household members purchased health insurance (1 if yes). Columns 3 and 4 present the first-stage regressions, associated with columns 1 and 2, respectively. Columns 5 and 6 show second stage regressions in relation to columns 1 and 2, respectively. Columns 1–4 are linear probability models estimated with OLS, while columns 5–6 are IV/2SLS estimates. Controls include rainfall shocks, the proportion of household spending on water and water-related infrastructure per month, its interaction with rainfall shocks, rural residency, male gender, age in years, log of real household consumption expenditure (along with its square), household size, and educational levels of the household head. The authors apply IHSTA for water scarcity and the share of household monthly water spending. Robust standard errors, clustered at the individual level, are presented in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

account for village fixed effects. Columns 1, 3, and 5 do not include additional control variables, while columns 2, 4, and 6 include those. Columns 1 and 2 present OLS estimates, indicating no statistically significant association between water scarcity and individual household member's decision to purchase health insurance. However, these findings may be biased due to endogenous water scarcity. This issue is addressed by using an IV/2SLS approach, where water scarcity is instrumented by temperature shocks.

The first-stage results provided in columns 3 and 4 of Table 2 show that rises in temperature shocks worsen water scarcity. An increase of one standard deviation in temperature shocks leads to around a 32–38% increase in water scarcity, holding all other factors constant. The IV/2SLS results are reported in columns 5 and 6 of the same table. Both results show that, after the IV/2SLS correction, water scarcity has a significant, positive effect on the likelihood of having health insurance. The model in column 6, with its richer specification, represents the preferred estimate. The analysis shows that for each 1% rise in water scarcity, there is an approximate 0.13 percentage points increase in the likelihood of purchasing health insurance. Given that approximately 5.3% of the sample possesses health insurance (see Table S1), this effect translates to a 2.5% increase. The effect is robust to the exclusion of other controls. The positive effect of water scarcity on having health insurance is not surprising. Insurance reduces the need for borrowing and high health care costs, and it increases access to hospitalization services in Ethiopia (Yilma et al. 2015; Shigute et al. 2020). Evidence from other middle-income and developed countries further supports these findings. In Germany, private health insurance reduces catastrophic and impoverishing expenditures, providing financial risk protection (Hengel et al. 2024). Insurance functions as a shock

absorber in China, helping people avoid the financial consequences of health shocks (Liu et al. 2022).

Other controls also predict health insurance uptake (Table S2, column 3). The results show that rural residents are more likely to be uninsured than their counterparts. This finding is in line with recent evidence from the United States (Admon et al. 2023). However, it contrasts with Merga et al. (2022), who reported higher insurance coverage among rural residents in Ethiopia. Households with a large number of members are less likely to own health insurance. This aligns with Adjei-Mantey and Horioka (2023), who report a 0.5 percentage point drop in enrollment per additional household member. Consumption expenditure itself does not have an effect. However, there is a clear nonlinear negative relationship between consumption and health insurance uptake. Specifically, as household consumption expenditure increases, the likelihood of having health insurance declines after some point. Prior evidence suggests insurance enrollment rises with income but falls beyond a certain level (Dillingh et al. 2016).

Furthermore, individuals in households with better-educated household heads are more likely to have health insurance than those with illiterate heads. This agrees with evidence reported from Ghana (Adjei-Mantey et al. 2023), Ethiopia (Moyehodie et al. 2022), and Nepal (Bhusal and Sapkota 2021).

Additional robustness checks

Three additional robustness checks validate the conclusions. First, the paper tests whether the results in Tables 1 and 2 remain robust when controlling for households' water disinfection habits (e.g., water boiling practices before drinking). Second, it accounts for both water boiling habits and

water sources during rainy season. Household water source choice (e.g., taps versus rivers) can serve as an imperfect indicator of perceived water quality. It reflects a preference for sources considered safe and reliable. The conclusions remain consistent as shown in columns 1–3 and 4–6 of Table S4, respectively. Third, it checks the sensitivity of the water scarcity coefficient in relation to changes in the definition of weather shocks by modifying Eq. (1) into:

$$Shock_{wht} = \ln(X_{wht}) - \ln(\bar{X}_{wht-1}) \quad (6)$$

The models are estimated based on both alternative shock definitions and use other nonlinear probit estimators. Overall, the conclusions remain robust to those shown in Table S4.

Heterogeneity

The second specific objective examines the heterogeneous effects of water scarcity based on whether households purify their drinking water and whether they have access to handwashing facilities with water. The findings of this analysis are detailed in columns 1–4 and 5–8 of Table 3, respectively. Table 3 starts by examining water purification habits as a crucial factor in predicting health outcomes. In households without water purification practices, individuals are more prone to diarrheal illness (column 1) and are more likely to purchase health insurance (column 3). However, households with water purification habits do not show a higher likelihood of diarrheal illness (column 2), but they are more inclined to have health insurance (column 4). This could indicate that households with water purification habits are more risk-averse. Differences in the availability of

handwashing facilities with water could also explain the heterogeneous responses. The absence of a handwashing plot with water increases both the likelihood of diarrheal illness (column 5) and the probability of purchasing health insurance (column 7). However, there is no effect on health outcomes based on the availability of handwashing facilities, as indicated in columns 6 and 8.

Threats to instrument validity

The key concern for the validity of the instrument is that temperature shocks could have a direct impact on the health outcomes. One way could be by lowering the water quality (Fukushima et al. 2000). Therefore, this paper uses the WQT data to examine the relationship between temperature shocks and water quality, considering microbiological and chemical indicators, as discussed in the data section.

First, the study examines the link between temperature shocks and the risk of *E. coli* contamination in water samples collected from both households and water sources. The results show that temperature shocks do not necessarily increase the risk of *E. coli* contamination in water samples taken from households (columns 1–3) and water points (columns 4–6) of Table S6. Second, chemical analyses provide measures of the fluoride levels, water hardness, and electroconductivity as indicators of water quality. Columns 7–9 confirm that temperature shocks do not significantly affect these measures of water quality in the data. The columns 1–9 of Table S6 jointly show that temperature shocks have no association with lower water quality. It is therefore believed that other channels are likely to be of minor importance.

Third, temperature shocks could affect health outcomes through an effect on nutrient intake and agricultural

Table 3 Heterogeneity effects

	Water purifying habit?				Availability of handwashing plot with water?			
	Diarrheal illness		Health insurance		Diarrheal illness		Health insurance	
	No	Yes	No	Yes	No	Yes	No	Yes
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Water scarcity (IHSTA)	0.568** (0.277)	− 3.634 (13.269)	0.071** (0.034)	0.299*** (0.109)	0.339** (0.132)	0.072 (0.096)	0.134*** (0.033)	0.066 (0.041)
Observations	7,205	851	16,418	2,535	4,162	515	17,916	2,358
Weak IV test statistics	18.69	11.49	62.59	22.86	14.04	12.97	65.50	32.44
IV significance at first stage	1%	1%	1%	1%	1%	1%	1%	1%
Common covariates								
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Village FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	No	No	Yes	Yes	No	No

Notes: This table explores the heterogeneity effects based on households' water purifying habits (columns 1–4) and the availability of handwashing plots with water on it (columns 5–8). Controls include rainfall shocks, the proportion of household spending on water and water-related infrastructure per month, its interaction with rainfall shocks, rural residency, male gender, age in years, log of real household consumption expenditure (along with its square), household size, and educational levels of the household head. The authors apply IHSTA for water scarcity and the share of household monthly water spending. Robust standard errors, clustered at the individual level, are presented in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

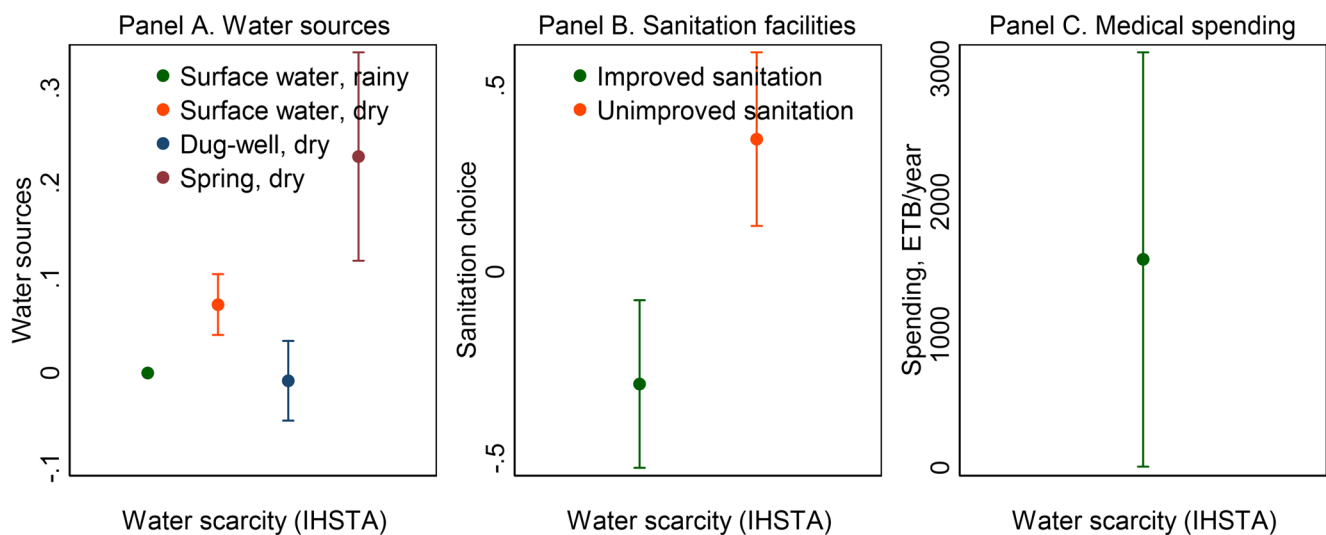


Fig. 2 Mechanisms. It shows whether a household uses each water source (panel A) and sanitation facility (panel B) in response to an increasing water scarcity. The answers are coded 1 if yes and 0 otherwise. Panel C is the amount of total medical expenses incurred by each household member within the preceding 12 months in Ethiopian Birr. Controls include rainfall shocks, the proportion of household spending on water and water-related infrastructure per month, its interac-

tion with rainfall shocks, the sources of water during the rainy season, rural residency, male gender, age in years, log of real household consumption expenditure (along with its square), household size, and educational levels of the household head. The authors apply IHSTA for water scarcity and the share of household monthly water spending. Robust standard errors clustered at the individual level are used

production. For instance, Huang et al. (2020) show that for every 1 °C increase in temperature, the time devoted to farm work decreases by 7%. This could have major welfare effects by limiting agricultural production and nutrition. Following Strauss and Thomas (2007), the robustness exercise tests the potential effect of temperature shocks on children's nutritional status using z-scores: height-for-age (HAZ), weight-for-age (WAZ), weight-for-height (WHZ), and body mass index (BMI). The results reported in columns 1–4 of Table S7 conclude that temperature shocks do not affect children's nutritional outcomes. The fact that the models control for wealth and its square further alleviates the concern regarding the temperature–nutrition channel.

Lastly, agents can use technologies (e.g., air conditioners, sun-protective clothing, better building designs, cooling centers, and fans) to mediate the adverse effects of temperature (Deschênes et al. 2009). But practically all of these services are inaccessible in rural Ethiopia, where 90% of this sample is drawn from. The authors cannot, however, conclusively rule out the direct possibility that temperature shocks could have some impact on health outcomes beyond the effect working through water scarcity.

Mechanisms

The third specific objective is to analyze the mechanisms behind the main results. It starts by examining the link between water scarcity and reliance on unimproved water sources. Figure 2, panel A portrays a positive association

between water scarcity and reliance on unprotected surface water during rainy season, surface water during dry season, and spring water during dry season. Earlier studies also corroborate this finding that interruptions in improved water supply drive households to collect water from unprotected sources (Chalchisa et al. 2017; Gebremichael et al. 2021).

In relation to sanitation facility choices, panel B illustrates that increasing water scarcity negatively impacts the use of improved sanitation facilities and is positively associated with the use of unimproved sanitation facilities. This aligns with prior studies showing that reduced water availability leads to increased open defecation (Dickinson et al. 2015; Coffey et al. 2017; Cameron et al. 2019), posing sanitation and health challenges (Spears 2020). Dependence on unimproved water and sanitation facilities in turn increases exposure to WASH-related diseases. Panel C of the same figure suggests that there is a positive and statistically significant relationship between water scarcity and annual medical expenses. This is consistent with results in Mebratie et al. (2019), where it is documented that participating in a CBHIS in Ethiopia reduces the cost per visit by at least 56% and boosts outpatient care utilization at public health facilities. Zhang et al. (2017) reach similar conclusions in the Chinese context.

Conclusions

This paper analyzes the association between water scarcity and health outcomes—diarrheal illness and health insurance ownership—using temperature shocks as an instrument for water scarcity. The findings show that:

- Water scarcity increases the likelihood of diarrheal illness in both adults and children under-seven as well as the probability of having health insurance.
- The associations are statistically significant in households lacking water purifying habits and handwashing facilities.
- Reliance on unimproved water sources, increased use of unimproved sanitation facilities, and higher medical spending drive the results.

From a public policy standpoint, the findings suggest the need to improve water supply and sanitation as well as strengthen health infrastructure in Ethiopia to reduce diarrheal illness. The results also suggest that water scarcity might prompt individuals to seek health insurance, which shows the importance of designing accessible and adaptive health insurance schemes that protect vulnerable households from climate-related health risks.

While the statistical tests support the credibility of the IV strategy, there are some methodological limitations. High temperature might directly affect individual health outcomes by deteriorating water quality, which could violate the exclusion restriction. Using microbiological and chemical WQT measures, it is tested whether temperature shocks increase *E. coli* contamination, which is a primary cause of diarrhea. This test shows no strong evidence of such validity problems. However, temperature could still influence other pathogens, such as *Vibrio cholerae*, for which no measure was available. Further, temperature increases have been shown to exacerbate preterm births, low birthweight (Cil and Kim 2022) and depression (Hua et al. 2023). Such direct health effects could affect the demand for health insurance, potentially violating the exclusion restriction. Therefore, while the evidence supports the exclusion restriction, the analysis cannot fully rule out the potential direct effects of temperature shocks on health. Similarly, self-reported disease prevalence could be subject to strategic incentives and subjective judgments, potentially biasing reporting within the designated time range. While empirical tests show no evidence of this, the authors cannot pretend that the problem does not exist.

Unobserved factors (e.g., health risk preferences) could also correlate with both perceived water scarcity and health insurance uptake. For example, risk-averse individuals can perceive water scarcity as more serious and are also more

likely to enroll in health insurance. This could limit the causal interpretation of the estimated relationship. While the IV estimates may reduce bias, they cannot fully address it if the instrument itself is correlated with unobserved confounders. Therefore, the estimates should be interpreted with caution.

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s40899-026-01328-6>.

Acknowledgements We thank Dr. Alper Elci, Editor-in-Chief, and four anonymous reviewers for their valuable comments. Bahre Gebru gratefully acknowledges financial support from the Environment for Development (EfD) initiative at the University of Gothenburg. He also thanks Yonas Alem for hosting his three-month research visit, during which the initial draft of this paper was written. Bahre particularly expresses gratitude to Gunnar Köhlin and Yonas Alem for arranging the visit. We are grateful to Yonas Alem, Kibrom Araya, and Franklin Amuakwa-Mensah for their useful comments on earlier versions of the paper. Any remaining errors are our own.

Author contribution Bahre Gebru: Conceptualization, Data curation, Methodology, Software, Formal Analysis, Writing-Original draft preparation, Writing-review and editing. Katarina Elofsson: Conceptualization, Supervision, Resources, Project Administration, Methodology, Formal Analysis, Writing-reviewing and editing.

Funding Open access funding provided by Uppsala University. The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

Data availability The ESS and WQT data are confidential and cannot be shared with third parties. However, interested readers can obtain these data for free by submitting an online request form to the World Bank. The link to the weather data, which is used to calculate weather shocks, is publicly accessible and can also be provided by the authors in Excel format. A Stata 18 do-file that replicates all the findings from the main text and Supplementary Information of this research is available upon request.

Declarations

Conflict of interest The authors declare that they have no known financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Abadie A, Athey S, Imbens GW, Wooldridge JM (2022) When should you adjust standard errors for clustering? *Q J Econ* 138:1–35. <https://doi.org/10.1093/qje/qjac038>
- Abera MG, Werkneh AA, Welde RS, Islam MA, Redae GH (2024) Diarrhea prevalence and water, sanitation, and hygiene (WASH) factors among internally displaced children under-five in Mekelle city, Northern Ethiopia. *Clin Epidemiol Glob Health* 28:101660. <https://doi.org/10.1016/j.cegh.2024.101660>
- Abrego-Pérez AL, Boonman TM, Valencia Arboleda CF (2025) Index insurance for simultaneous flooding and drought risks with insufficient data: a two-step approach. *Stoch Environ Res Risk Assess* 39:2769–2788. <https://doi.org/10.1007/s00477-025-02966-6>
- Achore M, Bisung E, Kuusaana ED (2020) Coping with water insecurity at the household level: a synthesis of qualitative evidence. *Int J Hyg Environ Health* 230:113598. <https://doi.org/10.1016/j.jheh.2020.113598>
- Adamu B, Ndi HN (2018) Changing trends in water sources and related pathologies in small to medium size African cities. *GeoJournal* 83:885–896. <https://doi.org/10.1007/s10708-017-9808-5>
- Adjei-Mantey K, Horioka CY (2023) Determinants of health insurance enrollment and health expenditure in Ghana: an empirical analysis. *Rev Econ Household* 21:1269–1288. <https://doi.org/10.1007/s11150-022-09621-x>
- Admon LK, Daw JR, Interrante JD, Ibrahim BB, Millette MJ, Kozhimannil KB (2023) Rural and urban differences in insurance coverage at pre-pregnancy, birth, and postpartum. *Obstet Gynecol* 141:570–581. <https://doi.org/10.1097/aog.0000000000005081>
- Agarwal S, Qin Y, Shi L, Wei G, Zhu H (2021) Impact of temperature on morbidity: new evidence from China. *J Environ Econ Manag* 109:102495. <https://doi.org/10.1016/j.jeem.2021.102495>
- Aina I, Ayinde O, Thiam D, Miranda M (2024) Crop index insurance as a tool for climate resilience: lessons from smallholder farmers in Nigeria. *Nat Hazards* 120:4811–4828. <https://doi.org/10.1007/s11069-023-06388-x>
- Ajjur SB, Al-Ghamdi SG (2021) Evapotranspiration and water availability response to climate change in the Middle East and North Africa. *Clim Chang* 166:28. <https://doi.org/10.1007/s10584-021-03122-z>
- Alem Y, Beyene AD, Köhlin G, Mekonnen A (2016) Modeling household cooking fuel choice: a panel multinomial logit approach. *Energy Econ* 59:129–137. <https://doi.org/10.1016/j.eneco.2016.06.025>
- Aragaw FM, Merid MW, Tebeje TM, Erkihun MG, Tesfaye AH (2023) Unimproved source of drinking water and its associated factors: a spatial and multilevel analysis of Ethiopian demographic and health survey. *BMC Public Health* 23:1455. <https://doi.org/10.1186/s12889-023-16354-8>
- Asgedom AA, Abirha BT, Tesfay AG, Gebreyowhannes KK, Abraha HB, Hailu GB, Abrha MB, Tsadik M, Gebrehiwet TG, Gebreyesus A, Desalew T, Alemayehu Y, Mulugeta A (2023) Unimproved water and sanitation contributes to childhood diarrhoea during the war in Tigray, Ethiopia: a community based assessment. *Sci Rep* 13:7800. <https://doi.org/10.1038/s41598-023-35026-6>
- Bah D, Gebru G, Hakizimana JL, Ogbonna U, Sesay B, Bah B, Mansaray P, Charles J, Jimmy A, Leno A, Jalloh F, Sengu N, Sogbeh S, Mansaray H, Kanneh L, Elduma AH (2022) Prevalence and risk factors of diarrheal diseases in Sierra Leone, 2019: a cross-sectional study. *Pan Afr Med J* 41:3. <https://doi.org/10.11604/pamj.2022.41.3.32403>
- Bandyopadhyay S, Kanji S, Wang L (2012) The impact of rainfall and temperature variation on diarrheal prevalence in Sub-Saharan Africa. *Appl Geogr* 33:63–72. <https://doi.org/10.1016/j.apgeog.2011.07.017>
- Belhassan K (2021) Water scarcity management. In: Vaseashta A, Maftei C (eds) *Water safety, security and sustainability: threat detection and mitigation*. Springer, Cham, pp 443–462
- Bellemare MF, Wichman CJ (2020) Elasticities and the inverse hyperbolic sine transformation. *Oxf Bull Econ Stat* 82:50–61. <https://doi.org/10.1111/obes.12325>
- Bhusal UP, Sapkota VP (2021) Predictors of health insurance enrolment and wealth-related inequality in Nepal: evidence from Multiple Indicator Cluster Survey (MICS) 2019. *BMJ Open* 11:e050922. <https://doi.org/10.1136/bmjopen-2021-050922>
- Birhanu Z, Sudhakar M, Jemal M, Hiko D, Abdulbari S, Abdisa B, Wolteji Chala B, Mitike G, Astale T, Berhanu N (2025) Households willingness to join and pay for community-based health insurance: implications for designing community-based health insurance based on economic Status in Ethiopia. *PLoS ONE* 20:e0320218
- Boelee E, Geerling G, van der Zaan B, Blauw A, Vethaak AD (2019) Water and health: from environmental pressures to integrated responses. *Acta Trop* 193:217–226
- Boone C, Glick P, Sahn DE (2011) Household water supply choice and time allocated to water collection: evidence from Madagascar. *J Dev Stud* 47:1826–1850. <https://doi.org/10.1080/00220388.2011.579394>
- Burbidge JB, Magee L, Robb AL (1988) Alternative transformations to handle extreme values of the dependent variable. *J Am Stat Assoc* 83:123–127. <https://doi.org/10.2307/2288929>
- Cameron L, Olivia S, Shah M (2019) Scaling up sanitation: evidence from an RCT in Indonesia. *J Dev Econ* 138:1–16
- Carr R, Kotz M, Pichler P-P, Weisz H, Belmin C, Wenz L (2024) Climate change to exacerbate the burden of water collection on women's welfare globally. *Nat Clim Chang* 14:700–706. <https://doi.org/10.1038/s41558-024-02037-8>
- Central Statistics Agency of Ethiopia and World Bank (2017) *Ethiopia Socioeconomic Survey, wave three (2015/2016) basic information document*. February 2017. World Bank, Washington DC
- Central Statistics Agency of Ethiopia and World Bank (2023) *Socio-economic Panel Survey (ESPS) Report - Wave 5, 2021/22*.
- Chalchisa D, Megersa M, Beyene A (2017) Assessment of the quality of drinking water in storage tanks and its implication on the safety of urban water supply in developing countries. *Environ Syst Res* 6:12. <https://doi.org/10.1186/s40068-017-0089-2>
- Chankrajang T (2019) State-community property-rights sharing in forests and its contributions to environmental outcomes: evidence from Thailand's community forestry. *J Dev Econ* 138:261–273
- Chen L, Jiao J, Liu S, Liu L, Liu P (2023) Mapping the global, regional, and national burden of diarrheal diseases attributable to unsafe water. *Front Public Health* 11:1302748. <https://doi.org/10.3389/fpubh.2023.1302748>
- Cil G, Kim J (2022) Extreme temperatures during pregnancy and adverse birth outcomes: evidence from 2009 to 2018 U.S. national birth data. *Health Econ* 31:1993–2024. <https://doi.org/10.1002/hec.4559>
- Coffey D, Spears D, Vyas S (2017) Switching to sanitation: understanding latrine adoption in a representative panel of rural Indian households. *Soc Sci Med* 188:41–50. <https://doi.org/10.1016/j.socscimed.2017.07.001>
- Cooke PA (1998) Intrahousehold labor allocation responses to environmental good scarcity: a case study from the hills of Nepal. *Econ Dev Cult Chang* 46:807–830. <https://doi.org/10.1086/452375>
- Couttenier M, Soubeyran R (2013) Drought and civil war in Sub-Saharan Africa. *Econ J* 124:201–244. <https://doi.org/10.1111/eoj.12042>
- Damania R, Desbureaux S, Zaveri E (2020) Does rainfall matter for economic growth? Evidence from global sub-national data

- (1990–2014). *J Environ Econ Manag* 102:102335. <https://doi.org/10.1016/j.jeem.2020.102335>
- Debaere P, Kapral A (2021) The potential of the private sector in combating water scarcity: the economics. *Water Secur* 13:100090. <https://doi.org/10.1016/j.wasec.2021.100090>
- Dehghani S, Massah Bavani A, Roozbahani A, Sahin O (2024) Assessment of climate change-induced water scarcity risk by using a coupled system dynamics and Bayesian network modeling approaches. *Water Resour Manag* 38:3853–3874. <https://doi.org/10.1007/s11269-024-03843-7>
- Dercon S, Christiaensen L (2011) Consumption risk, technology adoption and poverty traps: evidence from Ethiopia. *J Dev Econ* 96:159–173. <https://doi.org/10.1016/j.jdeveco.2010.08.003>
- Deschênes O, Greenstone M, Guryan J (2009) Climate change and birth weight. *Am Econ Rev* 99:211–217
- Dickinson KL, Patil SR, Pattanayak SK, Poulos C, Yang J-H (2015) Nature's call: impacts of sanitation choices in Orissa, India. *Econ Dev Cult Chang* 64:1–29. <https://doi.org/10.1086/682958>
- Dillingh R, Kooreman P, Potters J (2016) Probability numeracy and health insurance purchase. *Economist* 164:19–39. <https://doi.org/10.1007/s10645-015-9258-8>
- Edamo ML, Bushira KM, Ukumo TY, Ayele MA, Alaro MA, Borko HB (2022) Effect of climate change on water availability in Bilate catchment, Southern Ethiopia. *Water Cycle* 3:86–99. <https://doi.org/10.1016/j.watcyc.2022.06.001>
- Ethiopian Health Insurance Agency (2015) Evaluation of Community-Based Health Insurance Pilot Schemes in Ethiopia: Final Report. Addis Ababa, Ethiopia
- Ethiopian Health Insurance Agency (2020) Community-based health insurance membership registration and contribution trends: 2011–2020. Addis Ababa
- Fisher AC, Rubio SJ (1997) Adjusting to climate change: implications of increased variability and asymmetric adjustment costs for investment in water reserves. *J Environ Econ Manag* 34:207–227. <https://doi.org/10.1006/jeem.1997.1011>
- Fotio HK, Nguea SM (2022) Access to water and sanitation in Africa: does globalization matter? *Int Econ* 170:79–91. <https://doi.org/10.1016/j.inteco.2022.02.005>
- Freeman MC, Stocks ME, Cumming O, Jeandron A, Higgins JPT, Wolf J, Prüss-Ustün A, Bonjour S, Hunter PR, Fewtrell L, Curtis V (2014) Systematic review: hygiene and health: systematic review of handwashing practices worldwide and update of health effects. *Trop Med Int Health* 19:906–916. <https://doi.org/10.1111/tmi.12339>
- Fukushima T, Ozaki N, Kaminishi H, Harasawa H, Matsushige K (2000) Forecasting the changes in lake water quality in response to climate changes, using past relationships between meteorological conditions and water quality. *Hydrol Process* 14:593–604.
- Gaffan N, Degbey C, Kpozehouen A, Ahanhanzo YG, Paraíso MN (2023) Exploring the association between household access to water, sanitation and hygiene (WASH) services and common childhood diseases using data from the 2017–2018 Demographic and Health Survey in Benin: focus on diarrhoea and acute respiratory infection. *BMJ Open* 13:e074332
- Galárraga O, Sosa-Rubí SG, Salinas-Rodríguez A, Sesma-Vázquez S (2010) Health insurance for the poor: impact on catastrophic and out-of-pocket health expenditures in Mexico. *Eur J Health Econ* 11:437–447. <https://doi.org/10.1007/s10198-009-0180-3>
- Gamper-Rabindran S, Khan S, Timmins C (2010) The impact of piped water provision on infant mortality in Brazil: a quantile panel data approach. *J Dev Econ* 92:188–200. <https://doi.org/10.1016/j.jdevco.2009.02.006>
- Garg T (2019) Ecosystems and human health: the local benefits of forest cover in Indonesia. *J Environ Econ Manag* 98:102271
- Gebremichael SG, Yismaw E, Tsegaw BD, Shibeshi AD (2021) Determinants of water source use, quality of water, sanitation and hygiene perceptions among urban households in North-West Ethiopia: a cross-sectional study. *PLoS ONE* 16:e0239502. <https://doi.org/10.1371/journal.pone.0239502>
- Gebru B, Bezru S (2014) Environmental resource collection: implications for children's schooling in Tigray, northern Ethiopia. *Environ Dev Econ* 19:182–200. <https://doi.org/10.1017/S1355770X13000454>
- Gebru B, Elofsson K, Amuakwa-Mensah F, Marbuah G (2025) Climate variability and its impact on sanitation facility choice in Ethiopia. *Discov Water* 5:43. <https://doi.org/10.1007/s43832-025-00238-6>
- Geere JL, Hunter PR (2020) The association of water carriage, water supply and sanitation usage with maternal and child health. A combined analysis of 49 multiple indicator cluster surveys from 41 countries. *Int J Hyg Environ Health* 223:238–247. <https://doi.org/10.1016/j.ijheh.2019.08.007>
- Girma M, Hussein A, Norris T, Genye T, Tessema M, Bossuyt A, Hadis M, van Zyl C, Goyol K, Samuel A (2024) Progress in water, sanitation and hygiene (WASH) coverage and potential contribution to the decline in diarrhea and stunting in Ethiopia. *Matern Child Nutr* 20:e13280. <https://doi.org/10.1111/mcn.13280>
- Gosling SN, Arnell NW (2016) A global assessment of the impact of climate change on water scarcity. *Clim Chang* 134:371–385. <https://doi.org/10.1007/s10584-013-0853-x>
- He C, Liu Z, Wu J, Pan X, Fang Z, Li J, Bryan BA (2021) Future global urban water scarcity and potential solutions. *Nat Commun* 12:4667. <https://doi.org/10.1038/s41467-021-25026-3>
- Hengel P, Blümel M, Siegel M, Achstetter K, Köppen J, Busse R (2024) Financial risk protection in private health insurance: empirical evidence on catastrophic and impoverishing spending from Germany's dual insurance system. *Health Econ Policy Law* 19:3–20
- Hope R, Thomson P, Koehler J, Foster T (2020) Rethinking the economics of rural water in Africa. *Oxf Rev Econ Policy* 36:171–190. <https://doi.org/10.1093/oxrep/grz036>
- Horrace WC, Oaxaca RL (2006) Results on the bias and inconsistency of ordinary least squares for the linear probability model. *Econ Lett* 90:321–327. <https://doi.org/10.1016/j.econlet.2005.08.024>
- Hua Y, Qiu Y, Tan X (2023) The effects of temperature on mental health: evidence from China. *J Popul Econ* 36:1293–1332. <https://doi.org/10.1007/s00148-022-00932-y>
- Huang K, Zhao H, Huang J, Wang J, Findlay C (2020) The impact of climate change on the labor allocation: empirical evidence from China. *J Environ Econ Manag* 104:102376
- Innes R, Cory D (2001) The economics of safe drinking water. *Land Econ* 77:94–117. <https://doi.org/10.2307/3146983>
- International Vaccine Access Center, Johns Hopkins Bloomberg School of Public Health (2020). Pneumonia and Diarrhea Progress Report
- Karlsson M, Ziebarth NR (2018) Population health effects and health-related costs of extreme temperatures: comprehensive evidence from Germany. *J Environ Econ Manag* 91:93–117. <https://doi.org/10.1016/j.jeem.2018.06.004>
- Kåresdotter E, Destouni G, Lammers RB, Keskinen M, Pan H, Kalantari Z (2025) Water conflicts under climate change: research gaps and priorities. *Ambio* 54:618–631. <https://doi.org/10.1007/s13280-024-02111-7>
- La Fuente S, Jennings E, Lenters JD, Verburg P, Kirillin G, Shatwell T, Couture R-M, Côté M, Vinnâ CLR, Woolway RI (2024) Increasing warm-season evaporation rates across European lakes under climate change. *Clim Chang* 177:173. <https://doi.org/10.1007/s10584-024-03830-2>
- Li X, Smyth R, Yao Y (2023) Extreme temperatures and out-of-pocket medical expenditure: evidence from China. *China Econ Rev* 77:101894. <https://doi.org/10.1016/j.chieco.2022.101894>

- Liu Y, Hao Y, Lu Z-N (2022) Health shock, medical insurance and financial asset allocation: evidence from CHFS in China. *Health Econ Rev* 12:52
- Loughran D, Pritchett L (1997) Environmental scarcity, resource collection, and the demand for children in Nepal. *Poverty, Environment, and Growth Working Paper No 19*
- Mapingure M, Makota RB, Chingombe I, Moyo E, Dzinamarira T, Moyo B, Mpofu A, Musuka G (2024) Water, sanitation, and hygiene-specific risk factors of recent diarrheal episodes in children aged under 5 years: analysis of secondary data from the multiple indicator cluster survey (MICS 2019). *IJID Regions* 12:100417. <https://doi.org/10.1016/j.ijregi.2024.100417>
- Mapuka FN, Nel W, Kalumba AM (2024) Exploring household water conservation methods in rural South Africa: a case of the Mbhashe and Mnquma local municipalities. *Sustain Water Resour Manag* 10:145. <https://doi.org/10.1007/s40899-024-01127-x>
- Mebrahtom S, Worku A, Gage DJ (2022) The risk of water, sanitation and hygiene on diarrhea-related infant mortality in eastern Ethiopia: a population-based nested case-control. *BMC Public Health* 22:343. <https://doi.org/10.1186/s12889-022-12735-7>
- Mebratie AD, Sparrow R, Yilma Z, Abebaw D, Alemu G, Bedi AS (2019) The impact of Ethiopia's pilot community based health insurance scheme on healthcare utilization and cost of care. *Soc Sci Med* 220:112–119. <https://doi.org/10.1016/j.socscimed.2018.11.003>
- Merga BT, Balis B, Bekele H, Fekadu G (2022) Health insurance coverage in Ethiopia: financial protection in the era of sustainable development goals (SDGs). *Health Econ Rev* 12:43. <https://doi.org/10.1186/s13561-022-00389-5>
- Merid MW, Alem AZ, Chilot D, Belay DG, Kibret AA, Asratie MH, Shibabaw YY, Aragaw FM (2023) Impact of access to improved water and sanitation on diarrhea reduction among rural under-five children in low and middle-income countries: a propensity score matched analysis. *Trop Med Health* 51:36. <https://doi.org/10.1186/s41182-023-00525-9>
- Millard-Stafford ML, Brown MB, Wittbrodt MT (2025) Perspectives on enhancing human performance in the heat: is the solution to simply “just add water”? *Sports Med Health Sci* 7:317–328. <http://s://doi.org/10.1016/j.smhs.2024.12.001>
- Mosa A, Grethe H, Siddig K (2020) Economy-wide effects of reducing the time spent for water fetching and firewood collection in Ethiopia. *Environ Syst Res* 9:20. <https://doi.org/10.1186/s40068-020-00189-y>
- Motuma A, Tolera ST, Alemu FK, Adare D, Argaw R, Birhanu A, Shiferaw K, Hunduma G, Letta S, Temesgen S, Ayana DA (2025) Prevalence and risk factors of diarrhea among under-five children in Ethiopia: a systematic review and meta-analysis. *BMC Public Health* 25:1815. <https://doi.org/10.1186/s12889-025-22939-2>
- Moyehodie YA, Mulugeta SS, Amare Yilema S (2022) The effects of individual and community-level factors on community-based health insurance enrollment of households in Ethiopia. *PLoS ONE* 17:e0275896. <https://doi.org/10.1371/journal.pone.0275896>
- Nankhuni F, Findeis J (2004) Natural resource-collection work and children's schooling in Malawi. *Agric Econ* 31:123–134. <https://doi.org/10.1016/j.agecon.2004.09.022>
- Nelson JA (1988) Household economies of scale in consumption: theory and evidence. *Econometrica* 56:1301–1314. <https://doi.org/10.2307/1913099>
- Olley J, Cvitanovic M, Ginige T, Bunt-MacRury L (2024) A systematic literature review of sustainable water management in South Africa. *Sustain Water Resour Manag* 10:162. <https://doi.org/10.1007/s40899-024-01135-x>
- Onohuean H, Nwodo UU (2023) Demographic dynamics of water-borne disease and perceived associated WASH factors in Bushenyi and Sheema districts of South-Western Uganda. *Environ Monit Assess* 195:864. <https://doi.org/10.1007/s10661-023-11270-1>
- Onyena AP, Sam K (2025) The blue revolution: sustainable water management for a thirsty world. *Discov Sustain* 6:63. <https://doi.org/10.1007/s43621-024-00631-6>
- Paulos AH, Carroll DA, Powers J, Campolo J, Kim DD, Cohn A, Pickering AJ (2025) Temperature and precipitation affect the water fetching time burden in Sub-Saharan Africa. *Nat Commun* 16:3486. <https://doi.org/10.1038/s41467-025-58780-9>
- Pessoa Colombo V, Chenal J, Koné B, Koffi JdA, Utzinger J (2023) Spatial distributions of diarrheal cases in relation to housing conditions in informal settlements: a cross-sectional study in Abidjan, Côte d'Ivoire. *J Urban Health* 100:1074–1086. <https://doi.org/10.1007/s11524-023-00786-z>
- Pullan RL, Freeman MC, Gething PW, Brooker SJ (2014) Geographical inequalities in use of improved drinking water supply and sanitation across sub-Saharan Africa: mapping and spatial analysis of cross-sectional survey data. *PLoS Med* 11:e1001626
- Radcliffe JC (2018) The water energy nexus in Australia—the outcome of two crises. *Water Energy Nexus* 1:66–85. <https://doi.org/10.1016/j.wen.2018.07.003>
- Raimann JG, Boaheng JM, Narh P, Matti H, Johnson S, Donald L, Zhang H, Port F, Levin NW (2020) Public health benefits of water purification using recycled hemodialyzers in developing countries. *Sci Rep* 10:11101. <https://doi.org/10.1038/s41598-020-68408-1>
- Rocha R, Soares RR (2015) Water scarcity and birth outcomes in the Brazilian semiarid. *J Dev Econ* 112:72–91. <https://doi.org/10.1016/j.jdeveco.2014.10.003>
- Russ J (2020) Water runoff and economic activity: the impact of water supply shocks on growth. *J Environ Econ Manag* 101:102322. <https://doi.org/10.1016/j.jeem.2020.102322>
- Saxton RE, Yeasmin F, Alam M-U, Al-Masud A, Dutta NC, Yeasmin D, Luby SP, Unicomb L, Winch PJ (2017) If I do not have enough water, then how could I bring additional water for toilet cleaning?! Addressing water scarcity to promote hygienic use of shared toilets in Dhaka, Bangladesh. *Trop Med Int Health* 22:1099–1111. <https://doi.org/10.1111/tmi.12914>
- Shigate Z, Strupat C, Burchi F, Alemu G, Bedi AS (2020) Linking social protection schemes: the joint effects of a public works and a health insurance programme in Ethiopia. *J Dev Stud* 56:431–448. <https://doi.org/10.1080/00220388.2018.1563682>
- Singh C, Osbahr H, Dorward P (2018) The implications of rural perceptions of water scarcity on differential adaptation behaviour in Rajasthan, India. *Reg Environ Chang* 18:2417–2432. <https://doi.org/10.1007/s10113-018-1358-y>
- Spears D (2020) Exposure to open defecation can account for the Indian enigma of child height. *J Dev Econ* 146:102277
- Srivastava S, Banerjee S, Debbarma S, Kumar P, Sinha D (2022) Rural-urban differentials in the prevalence of diarrhoea among older adults in India: evidence from Longitudinal Ageing Study in India, 2017–18. *PLoS ONE* 17:e0265040. <https://doi.org/10.1371/journal.pone.0265040>
- Staiger D, Stock JH (1997) Instrumental variables regression with weak instruments. *Econometrica*. <https://doi.org/10.2307/2171753>
- Stock JH, Wright JH, Yogo M (2002) A survey of weak instruments and weak identification in generalized method of moments. *J Bus Econ Stat* 20:518–529. <https://doi.org/10.1198/073500102288618658>
- Strauss J, Thomas D (2007) Health over the life course. In: Schultz TP, Strauss J (eds) *Handbook of development economics*, vol 4. Amsterdam, North-Holland
- UNICEF (2015) Water supply and sanitation in Ethiopia: turning finance into service for 2015 and beyond, an AMCOW country

- status overview. Nairobi., UNICEF (United Nations Children's Fund)
- UNICEF and WHO (2019) Progress on household drinking water, sanitation and hygiene 2000–2017: special focus on inequalities. New York.
- Usman MA, Gerber N, von Braun J (2019) The impact of drinking water quality and sanitation on child health: evidence from rural Ethiopia. *J Dev Stud* 55:2193–2211
- Wassie GT, Tadesse G, Nebeb GT, Melese AA, Ayalew AF, Bantie GM (2023) Determinants of household dropout from community-based health insurance program in northwest Ethiopia; a community-based case-control study. *PLoS ONE* 18:e0276676
- White C (2017) The dynamic relationship between temperature and morbidity. *J Assoc Environ Resour Econ* 4:1155–1198. <https://doi.org/10.1086/692098>
- WHO (2011) Guidelines for drinking-water quality. Fourth edition.
- WHO (2024) Diarrhoeal disease.
- Wooldridge JM (2010) *Econometric analysis of cross section and panel data*. MIT Press, Cambridge
- World Bank (2023) Tracking universal health coverage: global monitoring report. Executive summary. World Health Organization and International Bank for Reconstruction and Development/The World Bank, Geneva
- Yilma Z, Mebratie A, Sparrow R, Dekker M, Alemu G, Bedi AS (2015) Impact of Ethiopia's community based health insurance on household economic welfare. *World Bank Econ Rev* 29:S164–S173. <https://doi.org/10.1093/wber/lhv009>
- Yoon PW, Black RE, Moulton LH, Becker S (1996) Effect of not breastfeeding on the risk of diarrheal and respiratory mortality in children under 2 years of age in Metro Cebu, The Philippines. *Am J Epidemiol* 143:1142–1148. <https://doi.org/10.1093/oxfordjournals.aje.a008692>
- Zhang A, Nikoloski Z, Mossialos E (2017) Does health insurance reduce out-of-pocket expenditure? Heterogeneity among China's middle-aged and elderly. *Soc Sci Med* 190:11–19. <https://doi.org/10.1016/j.socscimed.2017.08.005>
- Zhao WZ, Wang JY, Zhang MN, Wu SN, Dai WJ, Yang XZ, Wang HG (2025) Global burden of diarrhea disease in the older adult and its attributable risk factors from 1990 to 2021: a comprehensive analysis from the global burden of disease study 2021. *Front Public Health* 13:1541492. <https://doi.org/10.3389/fpubh.2025.1541492>

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.