Unsafe Waters: The Hidden Costs of Seasonal Drinking Water Contamination in Ecuador

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Motivation & Context

- Globally: **1.7 billion** diarrheal episodes/year; **443,832** under-5 deaths annually; **~60%** attributable to unsafe WASH (World Health Organization, 2024).

- Evidence: Rainy-season E. coli spikes → diarrhea; pathway unclear; water-quality interventions ↓ child mortality **~30%** (Kraay et al., 2022; Kremer et al., 2023)

- Context: in Ecuador **20%** children under 5 diarrhea
  - **37%** live in households drink E.coli contaminated water
  - **25%** stunting prevalence

- Opportunity: Ecuador national household health surveys + E. coli contamination in drinking water sources.

Full causal pathway: Rainfall → Contamination → Health

Preview of Main Findings

Finding 1

Rainfall → Contamination

- ↑ **+1 SD** rainfall → **+1.0 pp** E. coli
- Inverted U-shape concentration-dilution
- Amplified after consecutive wet shocks

Finding 2

Contamination → Health

- Peak at 1–3 months
- ↑ **+1.2–1.6 pp** diarrhea (**6–8%**)
- Biologically plausible lags

Finding 3

Limited Protection

- ✔ Good WASH: **50%** lower contamination
- ⚠ Rainfall shocks: Poor vs. Good **no difference**

Contents

- Introduction and Contribution
- Theoretical Framework
- Data and Empirical Strategy
- Results
- Robustness and Heterogeneity
- Conclusions

Introduction and Contribution

Research Questions

- Q1: How do rainfall shocks affect water contamination?
  H1: Shocks follow a concentration-dilution pattern

- Q2: What is the temporal pathway from contamination to health?
  H2: **Health issues peak with a lag**

- Q3: Can household WASH practices protect children when infrastructure is stressed by weather?

Contribution to Literature

1. **Environmental determinants of child health** Kremer et al. (2023); Levy et al. (2016); Kostyla et al. (2015)
   - Trace complete pathway rainfall → contamination → health

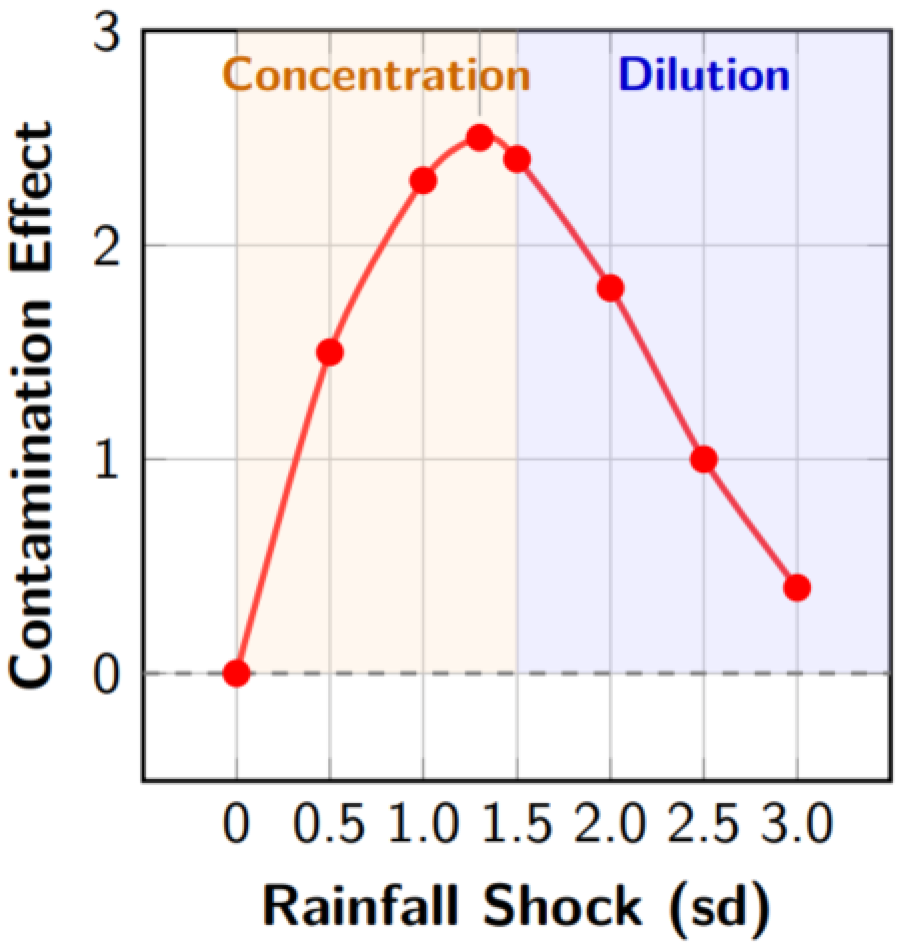
2. **Seasonality and adaptation** Aydamo et al. (2014); Augenblick et al. (2024); Gitter and McGavock (2024); Bevis et al. (2019); Pearson et al. (2016); Maccini and Yang (2009)
   - Seasonality around water-quality shocks

3. **Precipitation & dynamic effects** Kraay et al. (2022); Ji et al. (2020); Schmidt (2015)
   - Evidence of concentration–dilution mechanism

4. **Infrastructure resilience and household adaptation** Cutler and Miller (2005); Nguyen et al. (2021)
   - Heterogeneous effects by household WASH practices

Theoretical Framework

Hypothesis 1: Concentration–Dilution Mechanism



1. **Concentration**
   - Low to moderate ($0 \to 1.5$ SD)
   - Mobilizes accumulated pathogens
   - Overwhelms water treatment

2. **Dilution**
   - Moderate to extreme ($1.5 \to 3+$ SD)
   - Large water volumes
   - Dilutes pathogen concentration

Hypothesis 2: Health Dynamics

Expected temporal pattern of health impacts:

Lag	Expected Response
Lag 0 (contemporaneous)	Minimal effect - exposure begins
Lag 1-3 months	Peak incidence - incubation and illness
Lag 4-6 months	Effects dissipate - recovery phase

Mechanism: Contaminated water → pathogen ingestion → incubation period → clinical illness → recovery

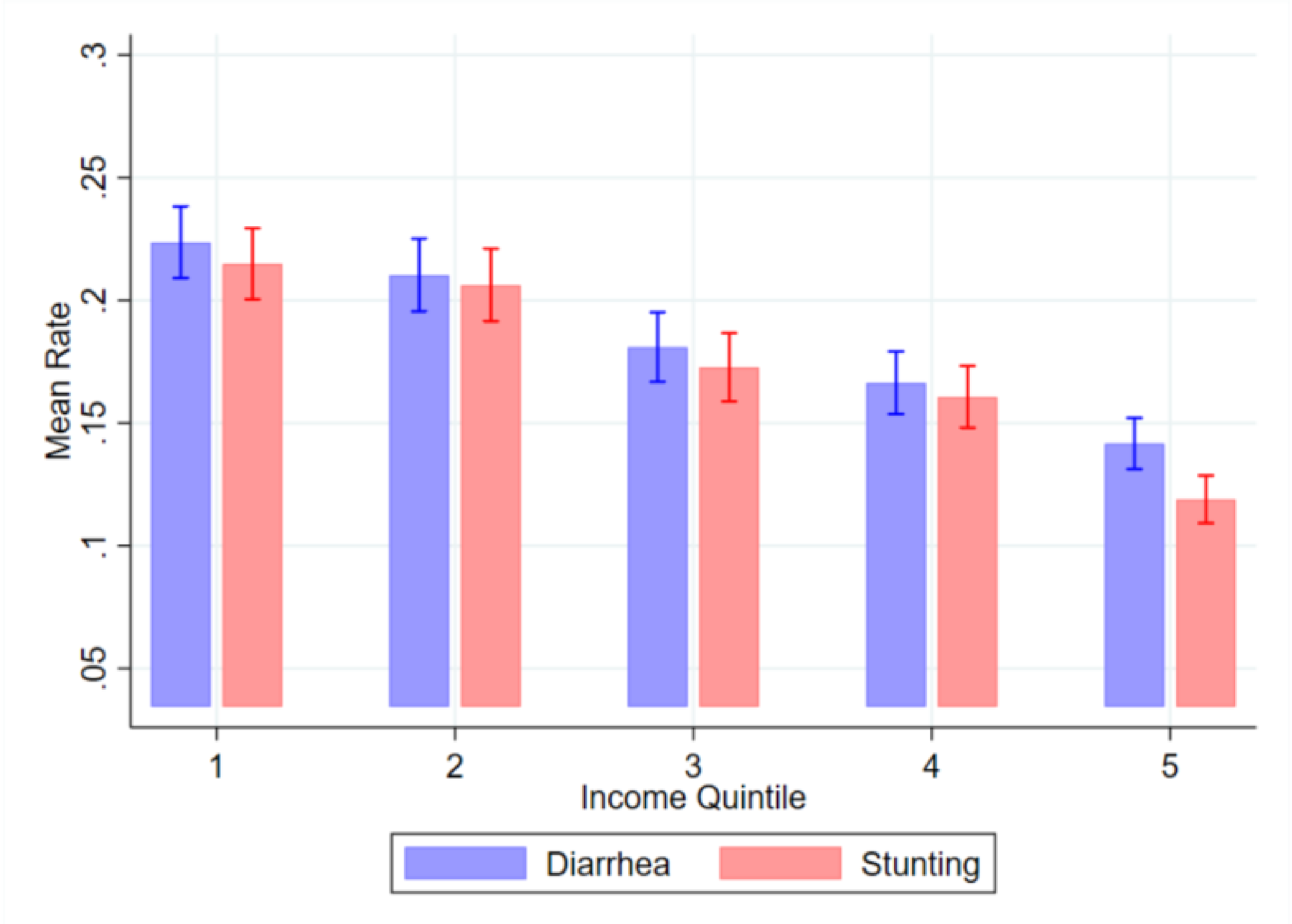
Data and Empirical Strategy

Data Sources

Source	Description
NCSS	National Child Stunting Surveys (2022-2024) ▪ Period: 2 waves, Jul 22 - Aug 24 ▪ Sample: 43,871 children under 5 ▪ E. coli testing at source & consumption ▪ Health outcomes: diarrhea, anthropometrics
CHIRPS	Climate Hazards Center - UC-SB ▪ Monthly rainfall 2000-2024 ▪ 5km resolution grid cells

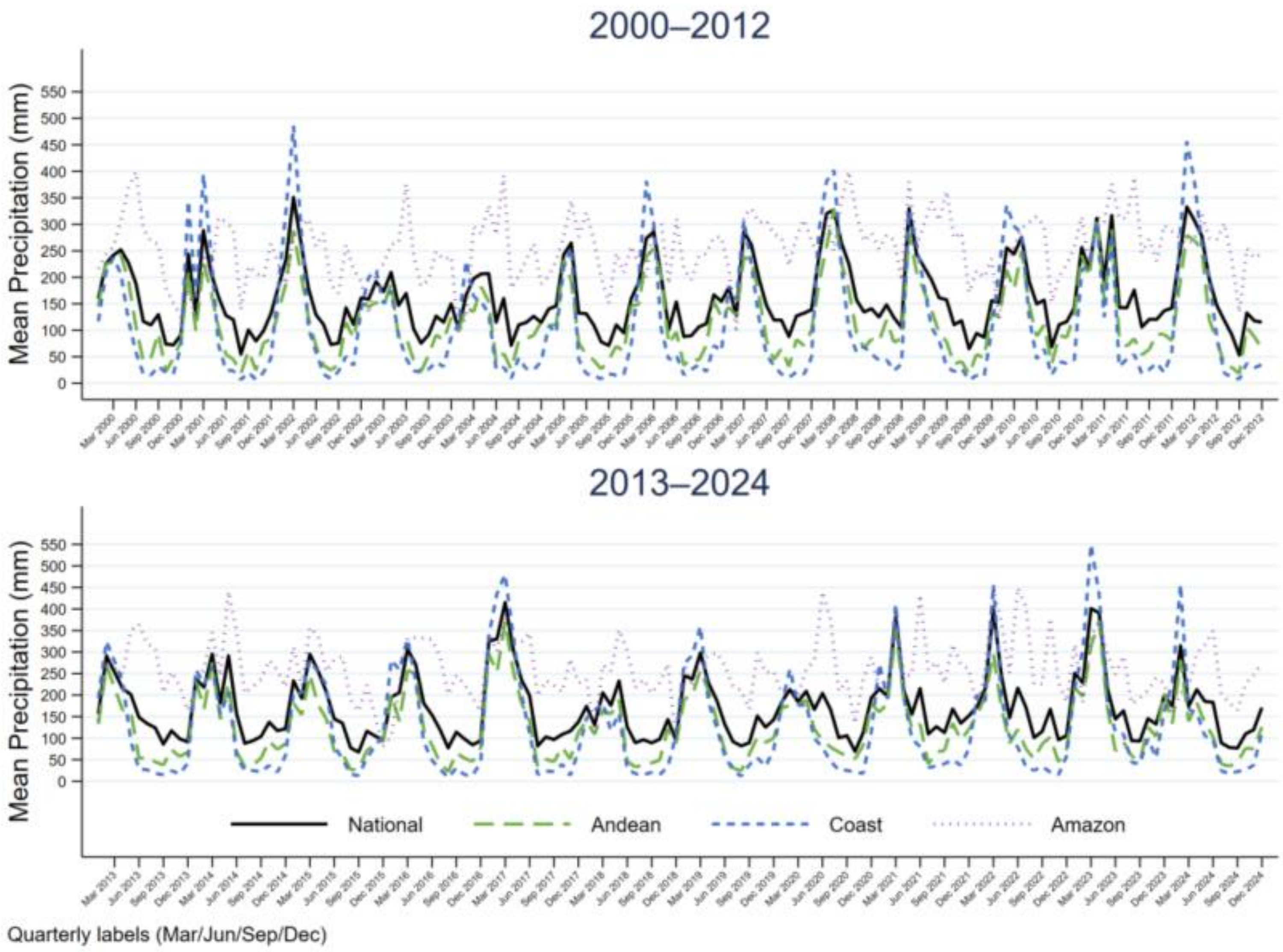
Evidence 1: Socioeconomic Gradients in Child Health

Figure 1: Child health outcomes by household income quintile



Evidence 2: Stable Seasonal Rainfall Patterns

Figure 2: Mean precipitation by natural region (mm)



Evidence 3: Precipitation, Contamination & Health

Figure 3a: E. coli and precipitation.

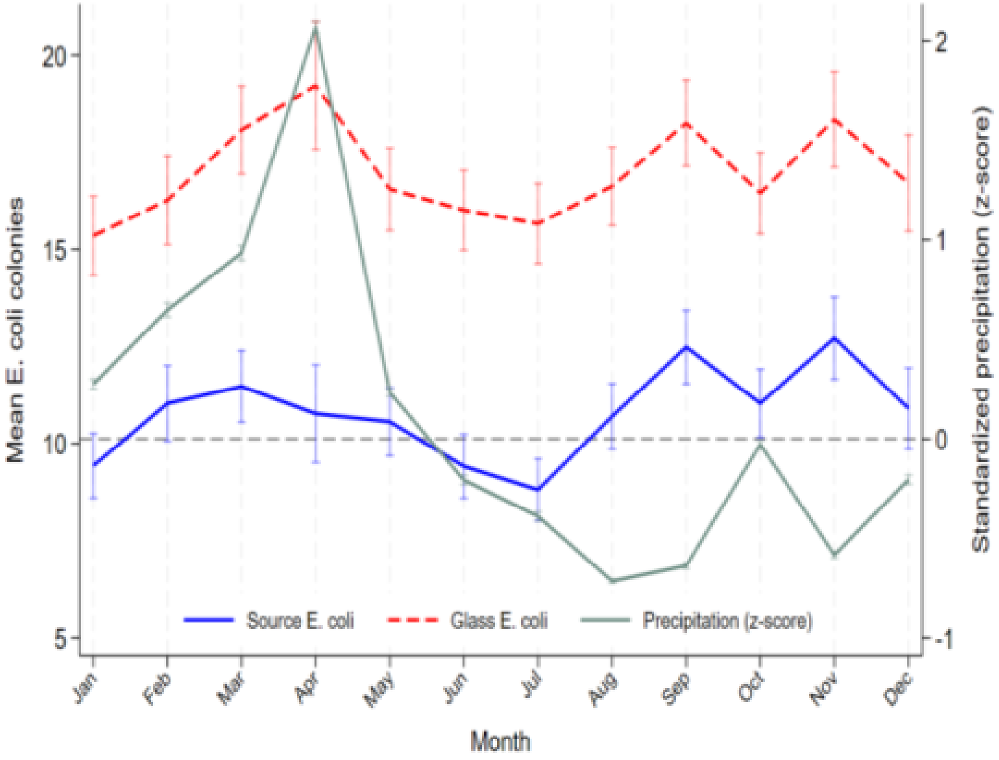
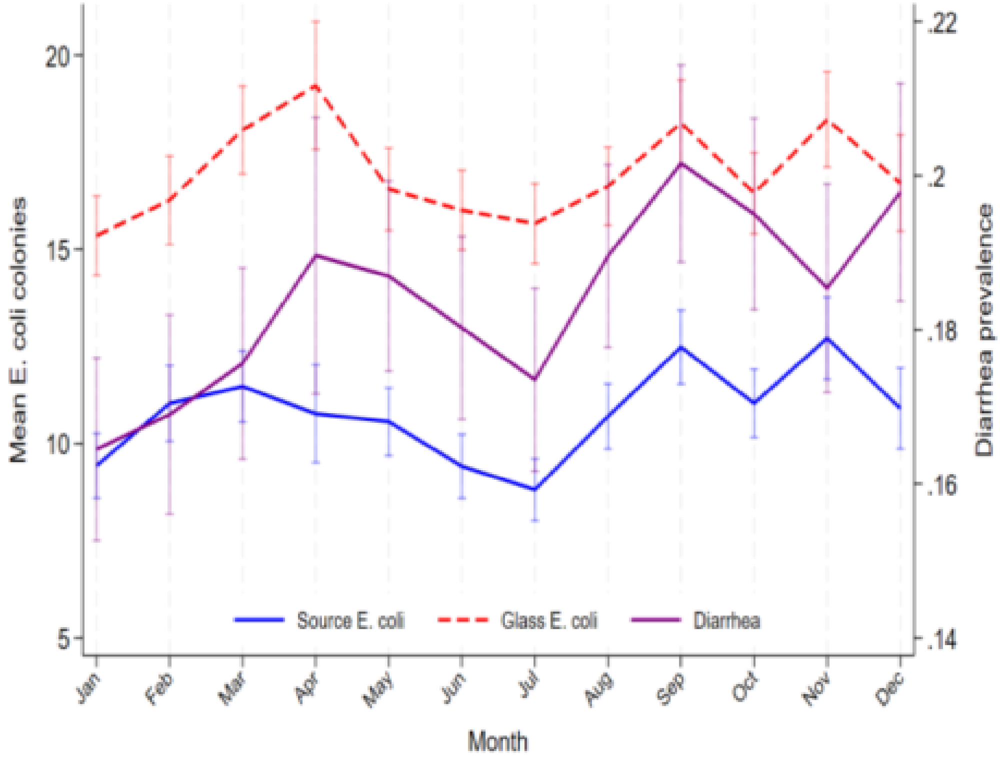


Figure 3b: E. coli and diarrhea.



Identification Strategy: Rainfall Shock Measure

Rainfall shock measure:

$$\text{Shock}_{ct} = \frac{(Precip_{ct} - Precip_{c,t-1}) - \mu_c^{22-24}}{\sigma_c^{22-24}}$$

Identifying assumptions:

1. Within-canton monthly variation is plausibly exogenous
2. Month-to-month changes capture relevant variation
3. Standardization ensures comparability diverse geography

Empirical Strategy: Hypothesis 1 (Rainfall → Contamination)

H1a: Nonlinearity (Concentration-Dilution)

$$y_{icrt} = \alpha_c + \rho_r + \lambda_m + \delta' X_{icrt} + \beta_1 s_{ct} + \beta_2 s_{ct}^2 + u_{icrt}$$

H1b: State Dependence (Lagged & current shocks)

$$y_{icrt} = \alpha_c + \rho_r + \lambda_m + \delta' X_{icrt} + \gamma s_{ct} + \theta s_{c,t-1} + \eta \left(s_{ct} \times s_{c,t-1} \right) + u_{icrt}$$

where: y_{icrt} = E.coli in glass,s = shock,α_c = canton FE, ρ_r = round FE, λ_m = month FE, X_{icrt} = controls

Empirical Strategy: Hypothesis 2 (Contamination → Health)

Dynamic Effects (Distributed Lags)

$$y_{icrt} = \alpha_c + \rho_r + \lambda_m + \delta' X_{icrt} + \sum_{k=0}^{6} \theta_k \, s_{Lk,ct} + e_{icrt}$$

where:

- y_{icrt} = Diarrhea presence, days
- $s_{Lk,ct} \equiv \text{shock}_{c,t-k}$ = rainfall shock lagged k months
- α_c = canton fixed effects
- ρ_r = survey round fixed effects
- λ_m = month-of-year fixed effects

Results

Result 1: Rainfall Shocks Increase Contamination

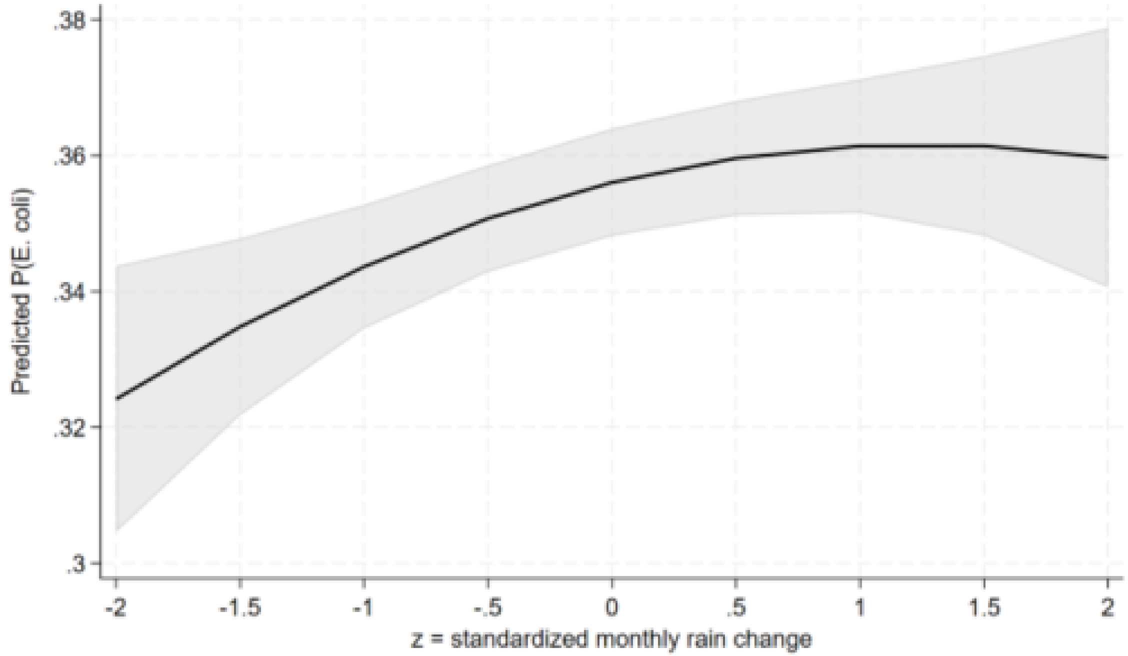
Table 1: Effects on E. coli detection

	(1) Linear	(2) FE linear	(3) FE quadratic	(4) FE interaction
Current rainfall shock (s)	0.020***	0.010***	0.009**	0.008**
	(0.004)	(0.004)	(0.003)	(0.004)
Shock squared			−0.004*	
			(0.002)	
Lagged shock (t-1)				0.008*
				(0.004)
Current × Lagged				0.007**
				(0.003)
Constant	0.328***	0.438***	0.443***	0.436***
	(0.011)	(0.020)	(0.021)	(0.020)
Obs.	42,551	42,330	42,330	42,330
Fixed Effects	No	Yes	Yes	Yes
R^2	0.013	0.242	0.243	0.243

Notes: Outcome = E. coli glass. All models include month FE; (2)-(4) add canton & wave FE, controls . SE clustered by canton. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Result 1a: Concentration-Dilution

Figure 4: Marginal effects on E. coli

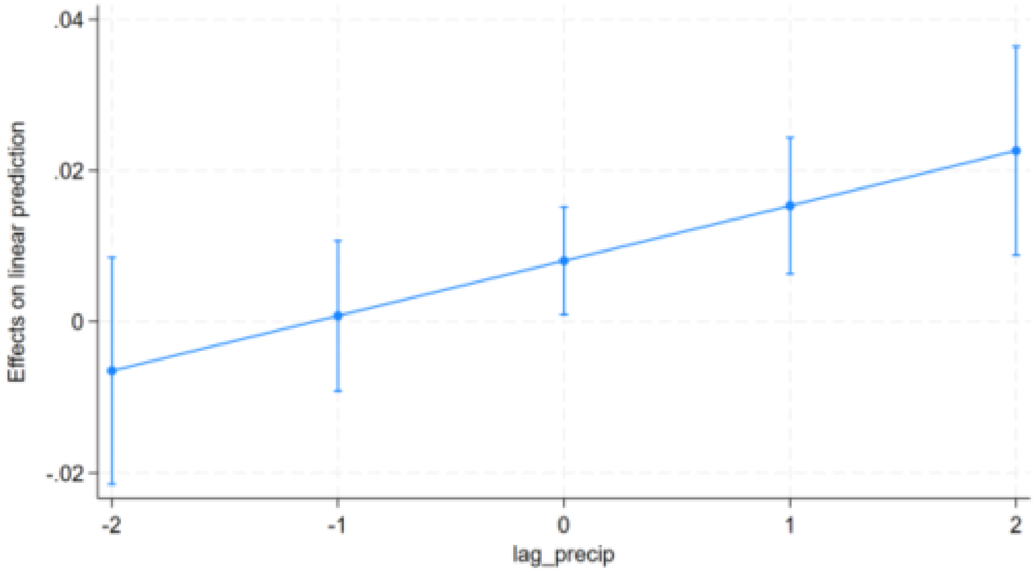


Inverted-U pattern:

- Linear: 0.009** (0.003)
- Quadratic : -0.004* (0.002)
- Peak at 1.26 SD

Result 1b: Cumulative Stress

Figure 5: Marginal effect by lagged s



Marginal effects:

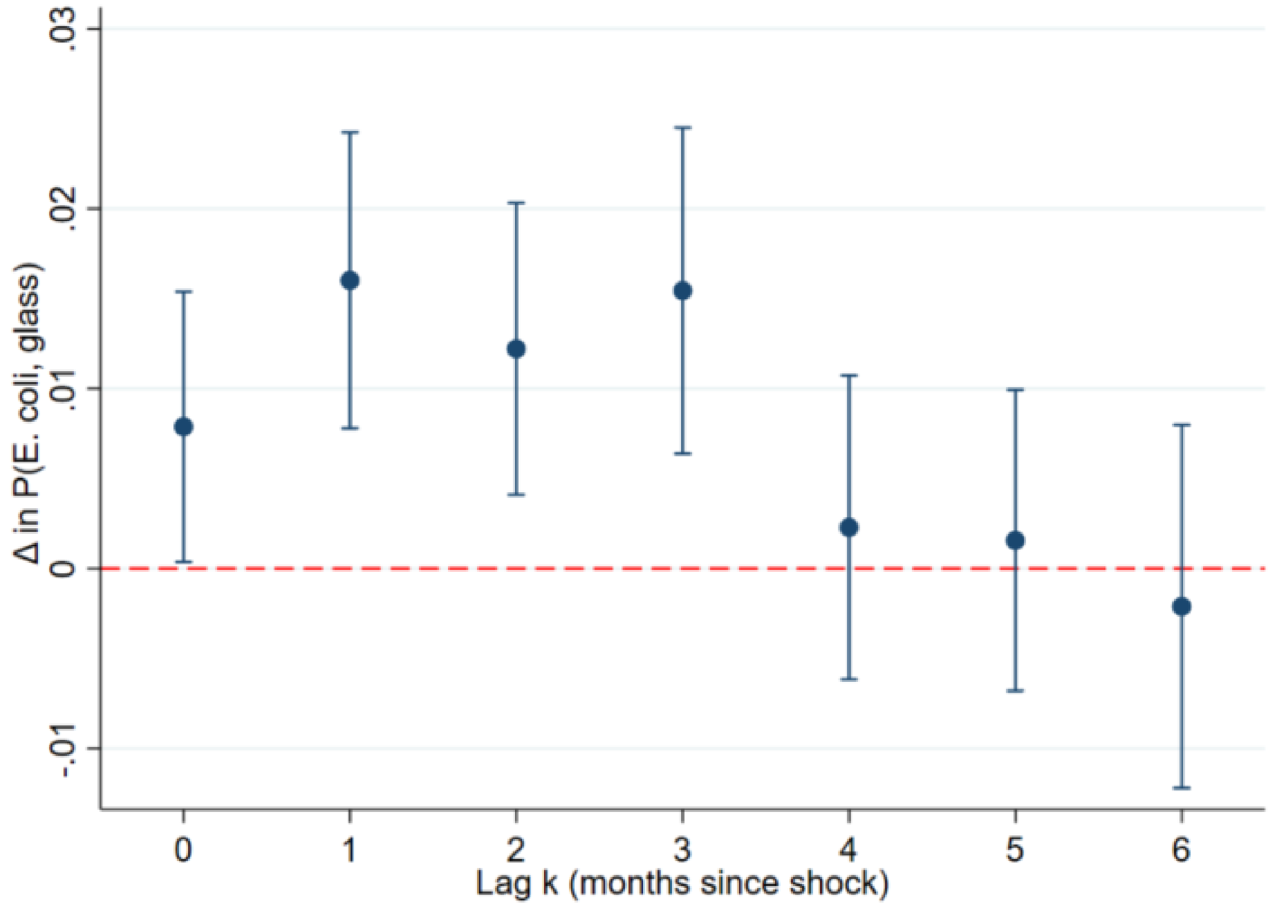
- After dry: near zero
- After normal: +0.8 pp
- After wet: +2.2 pp

Mechanism:

- Consecutive shocks **saturate sewerage capacity**

Result 2: Lagged Health Impacts - Dynamic Pattern

Figure 6: Diarrhea Distributed lag estimates



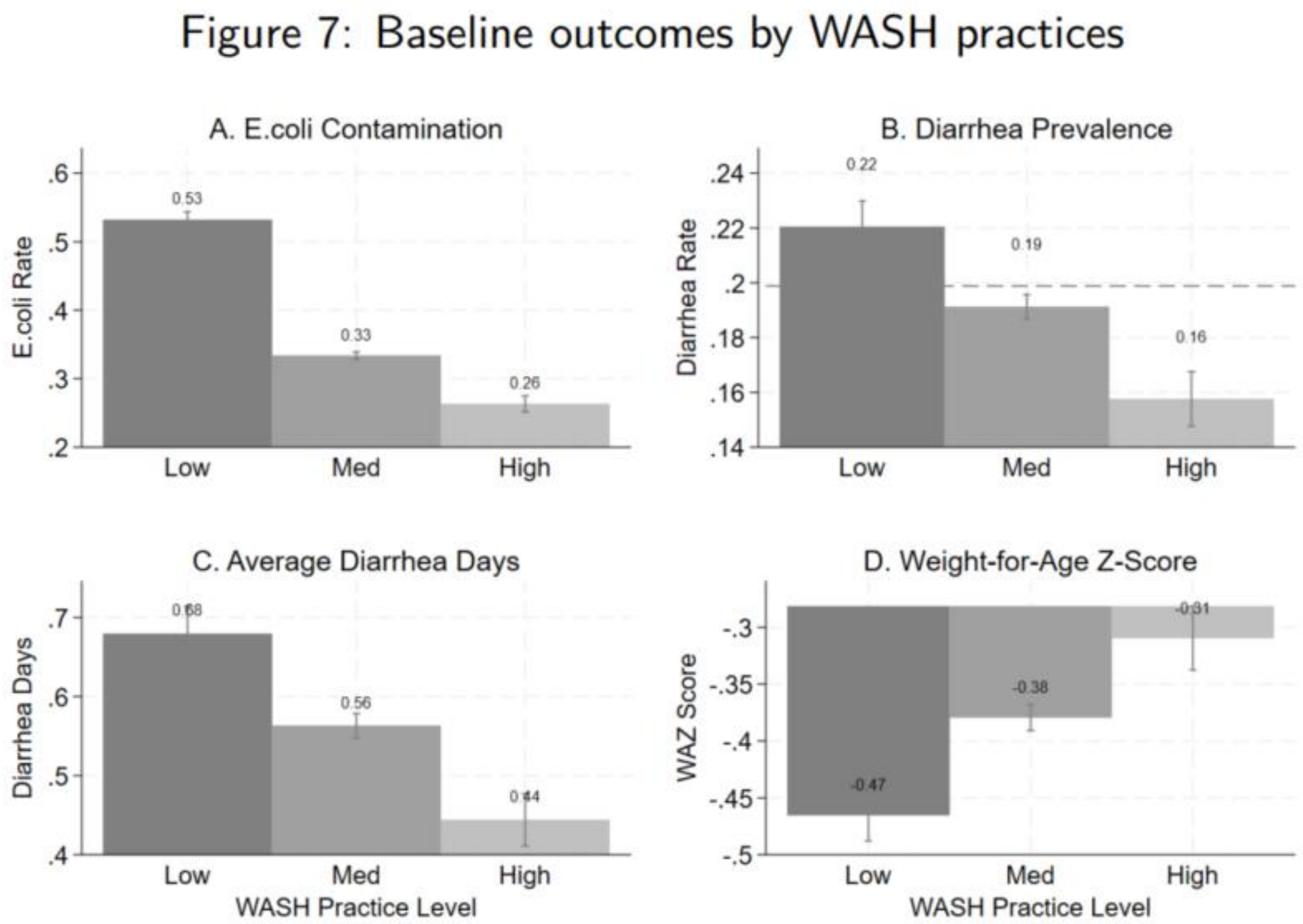
Result 2: Lagged Health Impacts - Regression Estimates

Table 2: Distributed lag effects on diarrhea

Lag k (months)	Diarrhea Prevalence	Diarrhea Days
0 (current month)	0.008**	0.005
	(0.004)	(0.014)
1 month	0.016***	0.039**
	(0.004)	(0.017)
2 months	0.012***	0.036**
	(0.004)	(0.017)
3 months	0.015***	0.037**
	(0.005)	(0.018)
4-6 months	≈0	≈0
	(ns)	(ns)
Obs.	41,234	41,234
Mean dep. var. (w)	0.190	0.561
SD dep. var. (w)	0.392	1.367

Notes: Outcome = diarrhea. SE clustered by canton. *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

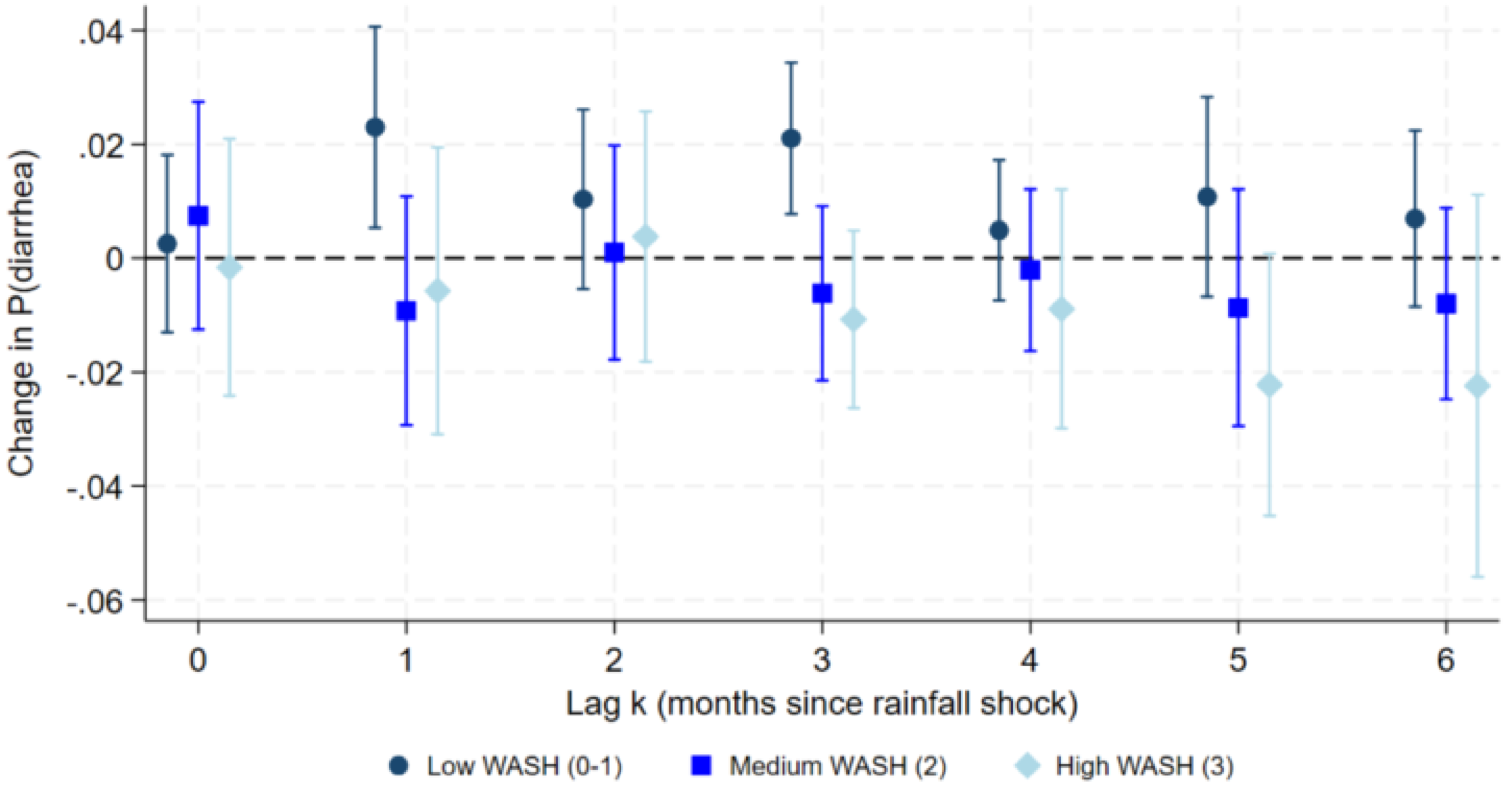
Result 3a: Clear gradient with WASH practices



Error bars show 95% confidence intervals. Numbers show mean values.
Low: 0-1 practices, Medium: 2 practices, High: 3 practices

Result 3b: WASH Limited Protection During Shocks

Figure 8: Diarrhea effects by household WASH practices



Gradient exists but CIs overlap

Result 3c: No WASH Protection on Cumulative Effects

Table 3: Cumulative effects E.coli on diarrhea by WASH (lags 0-4)

WASH Level	Effect
Poor (0-1 practices)	+6.20 pp*** (0.0079)
Good (2-3 practices)	+5.10 pp*** (0.0033)
Difference (Good - Poor)	-1.10 pp ($p=0.706$)
Percentage reduction	17.7%

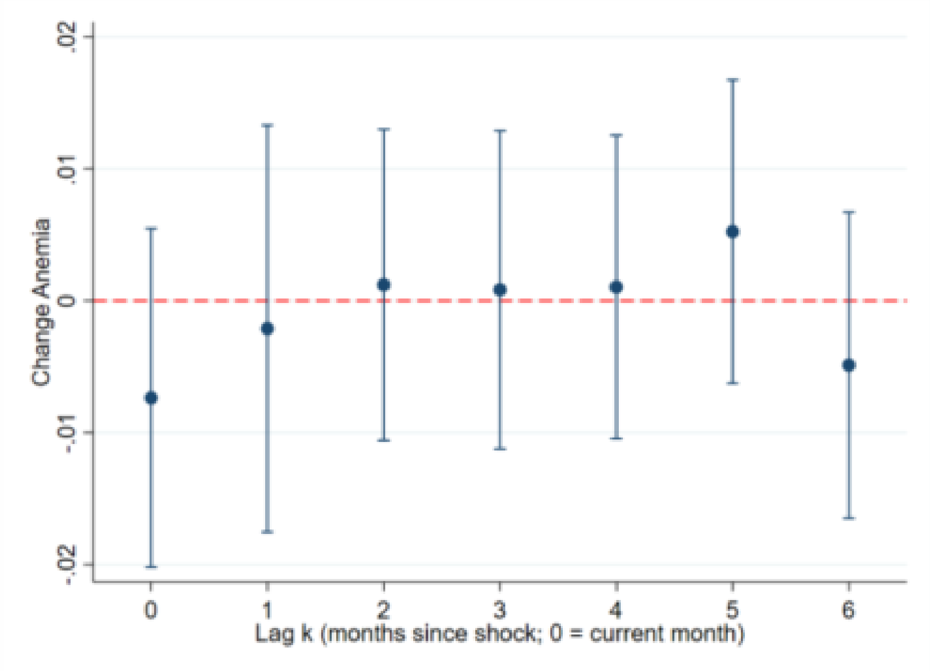
Notes: Outcome = diarrhea. SE clustered by canton.

*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

Robustness and Heterogeneity

Robustness: Placebo Test with Anemia

Figure 9: E.coli effects on anemia



Anemia:

- Reflects longer-run nutrition (iron deficiency)
- Should not respond to transitory shocks

Results:

- All coefficients near zero
- No statistical significance at any lag

Heterogeneity Analysis

Table 4: Heterogeneous Effects on Diarrhea

Dimension	Total Effect (0-4)	Differential
By Wealth Tercile		
Poor (reference)	4.8 pp	–
Middle	7.1 pp	+2.3 pp
Rich	2.1 pp	-2.7 pp
By Location		
Rural (reference)	5.1 pp	–
Urban	5.4 pp	+0.3 pp
By Region		
Coast (reference)	4.7 pp	–
Sierra	6.2 pp	+1.5 pp
Amazon	-6.3 pp	-11.0 pp***

Note: Differential = interaction effects summed across lags 0-4.

Conclusions

Conclusions and Policy Implications

1. +1 SD rainfall shock → +1.0 pp E. coli (inverted U pattern peaks at 1.26 SD, amplified after wet months)
   → Target resources during moderate rainfall events that follow wet periods

2. Health impacts peak 1-3 months post-shock (6-8% increase)
   → Water treatment campaigns and surge healthcare capacity

3. WASH practices reduce baseline risk by 50% but provide limited protection during shocks (6.2 pp vs 5.1 pp, p=0.706)
   → Upgrade sewer infrastructure for extreme events, preventive practices are insufficient

Guayas - Ecuador, March 1998

Thank You!

Questions?

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Thank You

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