Reducing Pathogen Risks in Drinking Water in the Developing World from the Household to the City Scale

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My commute to work....
Millennium Development Goals

- Adopted by UN General Assembly in 2000
- Target 10, Goal 7:
  - Reduce by 50% by 2015 the number of people without sustainable access to improved water and sanitation
  - Baseline 1990

![Graph showing global progress towards the MDG target](image)
ACCESS TO IMPROVED WATER

JMP, 2010
ACCESS TO IMPROVED SANITATION

JMP, 2010
**Types of Pathogens in Water**

**Viruses:** Hepatitis A, Norovirus, Adenovirus

**Bacteria:** *Vibrio cholera*, *Salmonella*, *Shigella*, *Campylobacter*

**Protozoa:** *Cryptosporidium*, *Giardia*, *Entamoeba*

**Helminths:** *Ascaris*, *Taenia*, *Schistosomes*, *Dracunculus*
IMPROVED DRINKING WATER SOURCES ARE NOT ALWAYS SAFE
TWO DIFFERENT APPROACHES

- Centralized water treatment and distribution
  - Managed by community or municipal utility
  - Existing service often poor
  - Example: Hubli-Dharwad, India

- Household water treatment
  - Individuals treat water themselves
  - Existing options have much room for improvement
  - Example: Solar Disinfection (SODIS)
ACCESS TO IMPROVED WATER

JMP, 2010
WHAT DOES ACCESS TO HOUSEHOLD PIPED WATER MEAN?

- **Water quality**
  - Data are scarce
  - (Effectively) treated or untreated?

- **Location**
  - In home vs in yard?

- **Timing**
  - Continuous or intermittent?
INTERMITTENT WATER SUPPLY

Hours of supply provided by major utilities

Hubli-Dharwad, Karnataka

- 1 million population

**Water Supply**
- >80% pop has piped water supply
- Service is for a few hours every 3-7 days
- Since 2007, 10% of the population has 24x7 water
- Public-private partnership

**Wastewater**
- Currently no treatment
- Many open sewers
WHY 24x7?

“The cracks used to suck external filth and sewage into the water pipes. The old water pipes had been laid very close to the underground drainage. This was the cause for constant waterborne diseases in the city.”

— M.K. Managond, senior engineer, Hubli-Dharwad

“This has been a miracle. We can turn the tap on anytime of day and there is water. It has freed me from worries. My children are cleaner and go to school. Others in the city envy my destiny now.”

— Girja Manjunath, resident of 24x7 pilot zone

from “India unprepared for urban boom” Washington Post, July 9, 2011
RESEARCH QUESTIONS

1. Does 24x7 water delivery improve health?
   • Diarrhea prevalence and improved anthropometric indicators in children under five
   • Explore variables that are on the causal pathway

2. Does 24x7 water delivery improve household economy?
   • Compare costs of continuous supply against the coping costs of intermittent delivery

3. Does 24x7 water delivery improve water quality at the tap and in homes?
   • What are the mechanisms of contamination in an intermittent system (infiltration, backflow, biofilm, stagnation)?
   • How can water quality in intermittent supplies be improved?
Research Questions

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Hubli-Dharwad Water System

Aminbhavi WTP

Dharwad

Neersagar WTP

Hubli
THE WATER SUPPLY

Malapraba Reservoir

Aminbavi Water Treatment Plant

Elevated Storage Reservoir

Ground Level Storage Reservoir
THE DISTRIBUTION SYSTEM
THE VALVES AND VALVEMEN (AND WOMAN)
HOUSEHOLD TAPS – THE GOOD
HOUSEHOLD TAPS – THE BAD
HOUSEHOLD TAPS – THE UGLY
HOUSEHOLD STORAGE CONTAINERS
STUDY DESIGN

4000 households: 2000 with 24x7, 2000 control
Longitudinal follow-up over 1 year (4 rounds) to track seasonal trends

Health
- Diarrhea and HCGI in children under 5 and caregiver
- Variables on the causal Pathway
  - Hygiene behavior
  - Sanitation
  - Storage behavior
  - Multiple sources
  - Income

Economic
- Water tariffs
- Water payments
- Medical-related expenditures
- Storage costs
- Secondary supplies
- Water treatment

Water Quality
- Sample ~ 10% of hh
  - Direct from Taps
  - Stored Water
- Distribution system
- Groundwater/secondary sources

Presenting results from Rounds 1 and 2
RESEARCH METHODS – WATER QUALITY

- Grab samples
  - Total coliform bacteria and *E. coli* (Colilert quantitray)
  - Total and free chlorine residual
  - Turbidity
  - Conductivity

Super Madhu
RESEARCH METHODS CONT.

- Continuous water quality at taps (YSI)
  - Chlorine residual
  - Turbidity
  - Conductivity
  - Temperature

- High frequency pressure sensor
  (Telelog, 4 times/second)
  - Supply pipes
  - Household taps
RESULTS
Turbidity in Tap Water

Empirical Cumulative Distribution Function – Turbidity

n=853
RESULTS
TOTAL COLIFORM IN TAP WATER

Empirical Cumulative Distribution Function – Total Coliform

n=823

Total Coliform (log scale, CFU/100mL)
RESULTS

CHLORINE VARIABILITY BETWEENWARDS

Free Chlorine – Intermittent Supply Wards

Free Chlorine – 24x7 Supply Wards
INTRA-WARD VARIABILITY

- Symbols = different sampling days
- Intermittent supply ward that is “worse-case” scenario
- Explore what occurs in course of a supply cycle
TRA-WARD

BILITY

- Symbols = different sampling days
- Intermittent supply ward that is “worse-case” scenario
- Explore what occurs in course of a supply cycle
TRA-WARD

VARIABILITY

- Symbols = different sampling days
- Intermittent supply ward that is “worse-case” scenario
- Explore what occurs in course of a supply cycle
Lowest allowable pressure in US: 20 psi
Aug 4 Supply Cycle, Rajdani Colony (service line):
Turbidity and E. coli

- Turbid+
- E. coli (log)
In 24x7, storage still occurs. Stored water quality deteriorates over time. Does it erase gains in improved quality of tap water?
ONGOING RESEARCH QUESTIONS

- Do the water quality improvements in 24x7 result in health benefits? (less diarrhea in children)
- Does 24x7 require more or less water?
- What are the costs of 24x7 compared to the benefits?
- How can we translate our research findings into recommendations for:
  - Hubli-Dharwad, and other cities interested in converting to 24x7?
  - Improving service and water quality for intermittent water supplies?
What should residents do to ensure their water is safe in the meantime?

Photo from “India unprepared for urban boom” Washington Post, July 9, 2011
HOUSEHOLD WATER TREATMENT (HWT)
Children demonstrating SODIS, Bolivia
SUNLIGHT INACTIVATION MECHANISMS

Direct damage by UVB
Well-accepted, mechanism fairly well characterized, rates not known

Indirect damage by endogenous sensitizers
Well-accepted, mechanism not well understood

Indirect damage by exogenous sensitizers
RADICAL idea, mechanism not understood

Temperature
> 50°C Pasteurization
< 50°C Synergistic

O₂
ROS

O₂
ROS
SUNLIGHT MATTERS!

[Images of children playing near a body of water]
**SUNLIGHT ENHANCES OXIDATIVE STRESS**

1. $O_2^-$ forms in ETC
2. Reacts with Fe-S clusters
3. Releases Fe
4. Fe binds to DNA
5. Reacts with $H_2O_2$
6. Produces $HO\cdot$
7. $HO\cdot$ damages DNA

Imlay (2003) *Annual Reviews in Microbiology*
ADDITIVES TO ACCELERATE OXIDATIVE STRESS

A) $\text{H}_2\text{O}_2 + \text{Citric Acid}$
   - Sodium Percarbonate (100 mg/L)
   - Citric Acid (100 mg/L)

B) $\text{H}_2\text{O}_2 + \text{Ascorbate + Copper}$
   - Sodium Percarbonate (100 mg/L)
   - Ascorbic Acid (20 mg/L)
   - $\text{CuCl}_2$ (0.02 mg/L)
MORE TRANSPARENT PLASTIC MATERIALS

![Graph showing the transmission of light through different plastic materials](image-url)
RESULTS

**E. coli inactivation during SODIS**

Inactivation faster for:

- Laboratory bacteria compared to wastewater bacteria

Field work conducted in Cochabamba, Bolivia

Similar results for Enterococci and MS2 coliphage
E. coli inactivation during SODIS

Inactivation faster for:
- Laboratory bacteria compared to wastewater bacteria
- PPCO compared to PET

Field work conducted in Cochabamba, Bolivia
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Inactivation faster for:

- Laboratory bacteria compared to wastewater bacteria
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- Additives A and B

Field work conducted in Cochabamba, Bolivia
Similar results for Enterococci and MS2 coliphage
IMPLICATIONS OF RESEARCH FINDINGS

- ASODIS
  - UVB-transparent containers
  - Additives

- Potential for
  - Higher pathogen inactivation
  - Increased acceptance by users?
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