Impact of a Water Quality Intervention on Typhoid Incidence in Urban India

Ayse Ercumen, PhD MPH
Division of Epidemiology
University of California, Berkeley

Ben Arnold
Emily Kumpel
Zachary Burt
Isha Ray
Kara Nelson
Jack Colford

May 1, 2015

9th International Conference On Typhoid and Invasive NTS Disease
Typhoid Fever Trends (Mortality per 100,000) and Sanitary Interventions, 1900-1936 [Source: Cutler and Miller 2005]
Typhoid Fever and Municipal Water Supply

Typhoid outbreak associated with municipal water consumption in Tajikistan (Mermin et al. 1999)

Typhoid fever associated with consumption of unboiled water from municipal supply in slum in Dhaka, Bangladesh (Ram et al. 2007)

Typhoid outbreak molecularly traced to municipal water supply in Nepal (Lewis et al. 2005)

Water systems characterized by inadequate chlorination, cross-connections with sewer lines and inadequate/intermittent water pressure in distribution pipelines

[Source: Mermin et al. 1999]
Many municipal piped water systems in low-income countries operate intermittently.

Sub-segments of distribution system receive water service on rotating basis.

[Source: van den Berg and Danilenko 2011]
Health Impact of Intermittent Water Supply

- Contamination of water in pipelines
- Contamination during household storage
- Reliance on unsafe water sources
- Limited water availability for hygiene
Health Impact of Intermittent Water Supply

- Contamination of water in pipelines
- Contamination during household storage
- Reliance on unsafe water sources
- Limited water availability for hygiene
Health Impact of Intermittent Water Supply

- Contamination of water in pipelines
- Contamination during household storage
- Reliance on unsafe water sources
- Limited water availability for hygiene
Health Impact of Intermittent Water Supply

- Contamination of water in pipelines
- Contamination during household storage
- Reliance on unsafe water sources
- Limited water availability for hygiene
Health Impact of Intermittent Water Supply

- Short-term intermittencies in continuous systems associated with diarrhea
  (Huang et al. 2011; Hunter et al. 2005; Nygard et al. 2007; Özkan et al. 2007)

- Chronic intermittent supply in low-income countries associated with increased waterborne illness
  (Abu Amr and Yassin 2008; Abu Mourad 2004; Cifuentes et al. 2002; Yassin et al. 2006)

- Longer intermittencies lead to higher risk
  (Ercumen et al. 2014)
Continuous Water Supply (24x7) in Hubli-Dharwad, India

- Twin cities in northern Karnataka with population of 1 million
- Over 80% of the population has access to municipal piped water
- 10% of city’s connections (~14,000 households) upgraded in 2007-2008
  - 24x7 water supply
  - Complete pipe replacement
  - Removal of public standpipes
- Rest of city continued to receive intermittent supply (every ~5 days)
Health Impact Evaluation of 24x7 Supply: Matched Cohort Study

- Pre-existing, non-randomized intervention
- Multivariate matching to identify comparable intermittent supply areas (Diamond and Sekhon 2013)
- Enrolled 3,922 households with children <5 years
- Longitudinal follow-up with quarterly visits over one year

24x7 Supply Wards and Selected Intermittent Supply Wards in Hubli-Dharwad (Ward: Administrative Unit)
Caregiver-Reported Health Outcomes

- Typhoid fever, cholera and hepatitis
  - Incidence in any household member since onset of 24x7
  - Diagnosis for these typically made in local informal clinics
  - Often symptom-based, with or without laboratory confirmation

- Child death
  - In children <2 yrs since onset of 24x7

- Diarrhea and blood/mucus in stool
  - Prevalence in children <5 yrs in week before interview
  - Diarrhea defined as ≥3 loose stools in any 24-hour period

- Cough/cold and scrapes/bruises
  - Prevalence in children <5 yrs in week before interview
  - Negative control outcomes - symptoms with no plausible association with 24x7 supply
Caregiver-Reported Health Outcomes

- **Typhoid fever, cholera and hepatitis**
  - Incidence in any household member since onset of 24x7
  - Diagnosis for these typically made in local informal clinics
  - Often symptom-based, with or without laboratory confirmation

- **Child death**
  - In children <2 yrs since onset of 24x7

- **Diarrhea and blood/mucus in stool**
  - Prevalence in children <5 yrs in week before interview
  - Diarrhea defined as ≥3 loose stools in any 24-hour period

- **Cough/cold and scrapes/bruises**
  - Prevalence in children <5 yrs in week before interview
  - Negative control outcomes - symptoms with no plausible association with 24x7 supply
Caregiver-Reported Health Outcomes

- Typhoid fever, cholera and hepatitis
  - Incidence in any household member since onset of 24x7
  - Diagnosis for these typically made in local informal clinics
  - Often symptom-based, with or without laboratory confirmation

- Child death
  - In children <2 yrs since onset of 24x7

- Diarrhea and blood/mucus in stool
  - Prevalence in children <5 yrs in week before interview
  - Diarrhea defined as ≥3 loose stools in any 24-hour period

- Cough/cold and scrapes/bruises
  - Prevalence in children <5 yrs in week before interview
  - Negative control outcomes - symptoms with no plausible association with 24x7 supply
Caregiver-Reported Health Outcomes

- Typhoid fever, cholera and hepatitis
  - Incidence in any household member since onset of 24x7
  - Diagnosis for these typically made in local informal clinics
  - Often symptom-based, with or without laboratory confirmation

- Child death
  - In children <2 yrs since onset of 24x7

- Diarrhea and blood/mucus in stool
  - Prevalence in children <5 yrs in week before interview
  - Diarrhea defined as ≥3 loose stools in any 24-hour period

- Cough/cold and scrapes/bruises
  - Prevalence in children <5 yrs in week before interview
  - Negative control outcomes - symptoms with no plausible association with 24x7 supply
Groups Well Balanced in Socioeconomics and Demographics

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>24x7 Participants</th>
<th>Intermittent Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean number of persons per household</td>
<td>6.5</td>
<td>6.5</td>
</tr>
<tr>
<td>Mean number of children &lt;5 yrs per household</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Mean age of primary caregiver of children &lt; 5 yrs</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Mean number of rooms in household</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>% of households with <em>pakka</em> roof</td>
<td>44</td>
<td>45</td>
</tr>
<tr>
<td>% of households with illiterate mother</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>
## Groups Well Balanced in Hygiene and Sanitation Indicators

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>24x7 Participants</th>
<th>Intermittent Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of households with handwashing facility:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside the household</td>
<td>74</td>
<td>74</td>
</tr>
<tr>
<td>In yard</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>No specific place</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>% of households with sanitation access:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Private latrine</td>
<td>91</td>
<td>92</td>
</tr>
<tr>
<td>Public latrine</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>No latrine</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>% of households with sewerage in vicinity:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Underground piped sewer</td>
<td>78</td>
<td>74</td>
</tr>
<tr>
<td>Open drain</td>
<td>72</td>
<td>75</td>
</tr>
</tbody>
</table>
## Impact on Severe Waterborne Illness

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Intermittent Incidence $^a$</th>
<th>24x7 Incidence $^a$</th>
<th>Cumulative Incidence Ratio (Adjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typhoid fever</td>
<td>61</td>
<td>34</td>
<td>0.58 (0.41, 0.78)</td>
</tr>
<tr>
<td>Hepatitis</td>
<td>27</td>
<td>34</td>
<td>1.13 (0.76, 1.73)</td>
</tr>
<tr>
<td>Cholera</td>
<td>2</td>
<td>4</td>
<td>1.48 (0.37, 6.92) $^b$</td>
</tr>
<tr>
<td>&lt;2 Child death</td>
<td>12</td>
<td>7</td>
<td>0.51 (0.22, 1.07)</td>
</tr>
</tbody>
</table>

$^a$ Incidence defined as number of households (per 1000) with at least one case since implementation of 24x7.

$^b$ Adjusted analysis not possible due to sparse data.
Impact on Typhoid Fever: Subgroup Analysis by Wealth

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Intermittent Incidence</th>
<th>24x7 Incidence</th>
<th>Cumulative Incidence Ratio (Adjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typhoid Fever</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Below median</td>
<td>60</td>
<td>32</td>
<td>0.53 (0.32, 0.83)</td>
</tr>
<tr>
<td>Above median</td>
<td>61</td>
<td>36</td>
<td>0.60 (0.38, 0.91)</td>
</tr>
</tbody>
</table>

Below vs. above median wealth determined based on quartiles of asset index calculated with principal component analysis.
## Impact on Child Diarrheal Illness

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Intermittent Prev %</th>
<th>24x7 Prev %</th>
<th>Prevalence Ratio (Adjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diarrhea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main analysis</td>
<td>8.4</td>
<td>7.9</td>
<td>0.93 (0.83, 1.04)</td>
</tr>
<tr>
<td>Below median</td>
<td>9.8</td>
<td>8.8</td>
<td>0.89 (0.76, 1.04)</td>
</tr>
<tr>
<td>Above median</td>
<td>7.0</td>
<td>6.9</td>
<td>0.98 (0.84, 1.16)</td>
</tr>
<tr>
<td>Blood/Mucus in Stool</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main analysis</td>
<td>1.9</td>
<td>1.5</td>
<td>0.78 (0.60, 1.01)</td>
</tr>
<tr>
<td>Below median *</td>
<td>2.5</td>
<td>1.6</td>
<td>0.63 (0.46, 0.87)</td>
</tr>
<tr>
<td>Above median *</td>
<td>1.2</td>
<td>1.4</td>
<td>1.08 (0.73, 1.63)</td>
</tr>
</tbody>
</table>

* Significant interaction (p=0.03)
## No Impact on Negative Control Outcomes

<table>
<thead>
<tr>
<th>Symptom</th>
<th>Intermittent Prev %</th>
<th>24x7 Prev %</th>
<th>Prevalence Ratio (Adjusted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cough/cold</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main analysis</td>
<td>41.5</td>
<td>41.1</td>
<td>1.00 (0.96, 1.05)</td>
</tr>
<tr>
<td>Below median</td>
<td>43.5</td>
<td>43.7</td>
<td>1.02 (0.95, 1.08)</td>
</tr>
<tr>
<td>Above median</td>
<td>39.4</td>
<td>38.4</td>
<td>0.98 (0.92, 1.05)</td>
</tr>
<tr>
<td>Scrape/bruise</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Main analysis</td>
<td>5.0</td>
<td>5.6</td>
<td>1.12 (0.97, 1.29)</td>
</tr>
<tr>
<td>Below median</td>
<td>5.5</td>
<td>6.1</td>
<td>1.12 (0.92, 1.35)</td>
</tr>
<tr>
<td>Above median</td>
<td>4.4</td>
<td>5.1</td>
<td>1.13 (0.91, 1.38)</td>
</tr>
</tbody>
</table>
Study Limitations

- Potential confounding from unobserved covariates
  - Observational study (randomization not feasible)
  - Exceptionally good balance between groups in observed covariates
  - No impact on negative control outcomes

- Non-differential measurement bias
  - Self-reported outcomes with no laboratory confirmation
  - Non-differential misdiagnosis with respect to study group would bias results towards null

- Differential measurement bias
  - Courtesy bias by recipients of 24x7 supply
  - No impact on least specific outcome (i.e., overall diarrhea) that is most vulnerable to biased recall
  - No impact on negative control outcomes
Study Limitations

- Potential confounding from unobserved covariates
  - Observational study (randomization not feasible)
  - Exceptionally good balance between groups in observed covariates
  - No impact on negative control outcomes

- Non-differential measurement bias
  - Self-reported outcomes with no laboratory confirmation
  - Non-differential misdiagnosis with respect to study group would bias results towards null

- Differential measurement bias
  - Courtesy bias by recipients of 24x7 supply
  - No impact on least specific outcome (i.e., overall diarrhea) that is most vulnerable to biased recall
  - No impact on negative control outcomes
Study Limitations

- Potential confounding from unobserved covariates
  - Observational study (randomization not feasible)
  - Exceptionally good balance between groups in observed covariates
  - No impact on negative control outcomes

- Non-differential measurement bias
  - Self-reported outcomes with no laboratory confirmation
  - Non-differential misdiagnosis with respect to study group would bias results towards null

- Differential measurement bias
  - Courtesy bias by recipients of 24x7 supply
  - No impact on least specific outcome (i.e., overall diarrhea) that is most vulnerable to biased recall
  - No impact on negative control outcomes
Conclusions

- Intermittent delivery of municipal water through piped networks associated with severe waterborne illness in this urban population

- 24x7 water supply associated with:
  - 42% reduction in typhoid fever incidence in study population
  - 37% reduction in bloody diarrhea prevalence in <5 children in low-income households
  - No overall impact on diarrhea in <5 children

- Scale up of 24x7
  - Ongoing effort to scale up to all of Hubli-Dharwad
  - Increased municipal water consumption per capita under 24x7
Acknowledgements

Funding
- Blum Center for Developing Economies
- NSF IRES Program
- Deshpande Foundation

Support
- Center for Multidisciplinary Development Research, Dharwad, India
- SDM College of Engineering, Dharwad, India
- Northern Karnataka Urban Water Supply and Drainage Board
Differential Impact of 24x7 by Socioeconomic Status

High Income Areas

67% have open drains
39% treat drinking water
61% use overhead tanks

Low Income Areas

80% have open drains
14% treat drinking water
8% use overhead tanks
## Water Handling Practices

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>% of 24x7 Participants</th>
<th>% of Intermittent Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obtains municipal water from:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Own connection</td>
<td>67</td>
<td>58</td>
</tr>
<tr>
<td>Shared connection</td>
<td>33</td>
<td>35</td>
</tr>
<tr>
<td>Public connection</td>
<td>&lt;1</td>
<td>6</td>
</tr>
<tr>
<td>Obtains water from borewell (public or private)</td>
<td>5</td>
<td>38</td>
</tr>
<tr>
<td>Treats drinking water</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Has handwashing facility with water</td>
<td>96</td>
<td>93</td>
</tr>
<tr>
<td>Retrieves drinking water from:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>From tap</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>From overhead tank</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>From storage container</td>
<td>77</td>
<td>83</td>
</tr>
</tbody>
</table>
### Water Handling Practices

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>% of 24x7 Participants</th>
<th>% of Intermittent Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obtains municipal water from:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Own connection</td>
<td>67</td>
<td>58</td>
</tr>
<tr>
<td>Shared connection</td>
<td>33</td>
<td>35</td>
</tr>
<tr>
<td>Public connection</td>
<td>&lt;1</td>
<td>6</td>
</tr>
<tr>
<td>Obtains water from borewell (public or private)</td>
<td>5</td>
<td>38</td>
</tr>
<tr>
<td>Treats drinking water</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>Has handwashing facility with water</td>
<td>96</td>
<td>93</td>
</tr>
<tr>
<td>Retrieves drinking water from:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>From tap</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>From overhead tank</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>From storage container</td>
<td>77</td>
<td>83</td>
</tr>
</tbody>
</table>
Both tap and stored water quality improved under 24x7.
However, contamination during storage was common.
Difference between 24x7 and intermittent supply was less pronounced in stored water than in tap water.

<table>
<thead>
<tr>
<th></th>
<th>% of samples positive for E. coli</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>24x7</td>
</tr>
<tr>
<td>Tap water</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Stored water</td>
<td>13</td>
</tr>
</tbody>
</table>