Influence of groundwater iron and fecal contamination on chlorination

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Chlorine-based disinfectants

• Kill pathogens in water
• Total chlorine = Chlorine demand + Residual chlorine
• Residual chlorine depends on chlorine demand
• CDC recommends residual chlorine 0.2-2 mg/L
• Important point-of-use disinfectant
Point-of-use chlorination in Bangladesh

- Earlier chlorination efforts were unsuccessful
  - Calcium hypochlorite
  - Sodium hypochlorite

- Chlorination with sodium dichloroisocyanurate (NaDCC)
  - High user compliance
  - Successful: 80% had residual chlorine
  - Improved the microbiological quality
  - Low diarrhea among children
Rationale

• icddr,b conducted a trial (Nov 11- Nov 12)
  – Sodium dichloroisocyanurate (NaDCC)
  – 15%-20% wells had no residual chlorine
  – Regular use of NaDCC reported
  – Participants wanted to know the reason

• We hypothesized high chlorine demand may result in no residual with:
  – High levels of groundwater chemicals: iron
  – High levels of groundwater contamination
Rationale of assessing iron

• Exists in two oxidation states
  – Fe$^{++}$ is soluble
  – Fe$^{+++}$ is insoluble
• In anaerobic conditions, iron is in Fe$^{++}$ form
• Fe$^{++}$ $\xrightarrow{\text{oxidation}}$ Fe$^{+++}$ $\xrightarrow{\text{chlorine}}$ High chlorine demand
• Ground water iron
  – No health hazards even in high concentrations
  – Bangladesh standard $\leq$ 1 mg/L
  – WHO recommends 0.3 - 3 mg/L
Rationale of assessing fecal contamination

- Tube wells and latrines are very close
- Open defecation
- 50% coverage of improved sanitation

Tube well and latrine
Objectives

• To assess variation of
  – Iron concentrations
  – Fecal contamination

• To assess if NaDCC provides the recommended residual
  – In groundwater with varying iron concentration
  – In groundwater with varying fecal contamination
Study sites

- 9 sub-districts of central Bangladesh
- low iron
Study design

Cross-sectional (N=654)

Phase 1
3 sub-districts
22 rural unions

Phase 2
6 sub-districts
65 rural unions

Village (66)
Tube well (264)

Village (390)
Tube well (390)
Water testing of tube well

Phase 1
- Iron
- Residual chlorine

Phase 2
- Iron
- Residual chlorine
- Fecal contamination
Iron concentration measurement

- Digital Hack pocket colorimeter
- 10 ml tube well water
- Add reagent
- Color change based on concentration of iron
Residual free chlorine measurement

- 10 L water in a container
- Add 33 mg NaDCC
- Shake the container
- Hach chlorine colorimeter
- 10 ml water after 30 min
- Add reagent
- Observe color change
Assessing fecal contamination

- **H$_2$S testing**
  - Presence-absence test
  - Field setting
  - Low sensitivity

- Collect water in 20 ml bottle

- Observe color change after 24 hrs
  - Black color: fecal contamination
  - No color change: no contamination
Results
Iron, residual chlorine and fecal contamination

- Iron concentration (N=654)
  - Median: 0.91 mg/L
  - 48% tube wells had >1 mg/L (Bangladesh Standard)
  - 18% tube wells had >3 mg/L (WHO upper limit)

- Residual free chlorine (N=654)
  - Median: 1.3 mg/L
  - 16% tube well had < 0.2 mg/L (CDC lower limit)

- 25% samples had 24 hours positive result (N=390)
Iron and chlorine interaction

Variation of median iron concentration and residual chlorine

unions
Iron and chlorine interaction

Number of tube wells (N=12)

Fe > 3mg/L  residual chlorine < 0.2 mg/L

Unions:
- Kaligonj
- Muktarpur
- Nagari
- Tumulia
- Barishaba
- Chandpur
- Durgapur
- Ghagoria
- Karihat
- Rayed
- Sanmania
- Singasree
- Toke
- Taragaon
- Barami
- Gazipur
- Gosinga
- Kaoral
- Mawna
- Prohalipur
- Raibari
- Telhathi
Factors influencing residual chlorine

<table>
<thead>
<tr>
<th>Factors influencing residual chlorine</th>
<th>Co-efficient</th>
<th>95% CI of co-efficient</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron concentration</td>
<td>-0.28</td>
<td>-0.31 -0.25</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Fecal contamination</td>
<td>0.07</td>
<td>-0.04 0.18</td>
<td>0.215</td>
</tr>
<tr>
<td>Intercept</td>
<td>1.50</td>
<td>1.44 1.57</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>
Discussion
Geochemical explanations for iron variation

• Groundwater iron depends on characteristics of aquifer
  – Aquifer materials vary spatially
  – Aquifer materials get dissolved in water
  – Iron content of aquifer materials high near surface
  – Ion exchange with sodium occurs as water flows down
Importance of recommended residual chlorine

- Contamination during storage time
  - unsafe storage containers
  - poor water handling practices
- Recontamination
- Limitation
  - Cross-sectional iron measurement
  - Seasonal variation
Conclusions

• High iron concentration lowered residual chlorine even in a area where iron concentration was generally low
• Mass chlorination interventions need to consider iron concentration to be successful
  – Increase chlorine dose
  – Reduce iron concentration
Recommendations

• Using other point-of-use disinfection method in areas with high groundwater content
• Double the dose of NaDCC if iron is high
  – unpleasant taste and smell
  – taste and smell taste using different doses
• Pilot study to prevent interaction of iron
  – household aeration process
  – iron removal technique
Acknowledgements

• Leanne Unicomb
• Steve Luby
• Eilidh Higgins
• Sania Ashraf
• Mahbubur Rahman
• Shaila Arman
• Ayse Ercumen
• Carrie Read
• Study participants
• Medentech
Thank you

Question?