INVESTIGATING THE POTENTIAL OF FIELD-BASED WATER QUALITY TESTING TO ASSESS GROUNDWATER AGGRESSIVITY AND CORROSION POTENTIAL OF HANDPUMP BOREHOLES IN NORTHERN UGANDA

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- Background
- Research Goals
- Materials and Methods
- Field Results & Data Analysis
- Conclusions and Recommendations
A MAJORITY OF BOREHOLES IN UGANDA ARE VARIATIONS OF THE INDIA MARK II HANDPUMP

U-Series Handpumps

<table>
<thead>
<tr>
<th>Pump Regime</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>U2*</td>
<td>32mm NB</td>
</tr>
<tr>
<td>U3*</td>
<td>Open Top Cylinder (OTC), 65mm NB</td>
</tr>
<tr>
<td>U3M</td>
<td>OTC &amp; corrosion resistant, 32m depth max</td>
</tr>
</tbody>
</table>

* Corrosion resistant if stainless steel riser pipes and pump rods used
RESEARCH GOALS

- To investigate efficacy of pH test strips to predict groundwater pH and aggressiveness,
- To compare the reliability and validity of 3 pH test strips to a Hanna pH probe,
- To determine the origin of iron measured at boreholes in Northern Uganda, and
- To provide recommendations to field workers and the district water authority concerning parameters to consider during borehole construction or rehabilitation.
MATERIALS AND METHODS
<table>
<thead>
<tr>
<th>Intended Use</th>
<th>Cost</th>
<th>Range (pH)</th>
<th>Test Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macherey Nagel (MN) pH-Fix test strips –REF 921</td>
<td>~$14 for 100 strips</td>
<td>0-14</td>
<td>10 sec/strip</td>
</tr>
<tr>
<td>(WaterWorks™) Extended Range pH Check Test Strips-481104</td>
<td>~$10 for 50 strips</td>
<td>2-12</td>
<td>30 sec/strip</td>
</tr>
<tr>
<td>Youth Waters pH Test Strips</td>
<td>~$10 for 160 strips</td>
<td>4.5-9</td>
<td></td>
</tr>
<tr>
<td>Hanna Instrument-HI 9813-5 probe</td>
<td>$175-200+</td>
<td>0.0-14.0</td>
<td></td>
</tr>
</tbody>
</table>
IRON CONCENTRATION WAS MEASURED AT EACH BOREHOLE USING THE SENSAFE™ IRON CHECK TEST KIT
A PUMP PERFORMANCE TEST WAS CONDUCTED AT 12 OF 15 BOREHOLES TO TEST FOR LEAKING

- RWSN pump test: 10 pumps or less for a 30 minute wait time (skat-RWSN, 2008, p.26)

- The pump was fully primed, left for two minutes, and then pumped until water flowed.

- Ideal number of pumps: 1
WATERAID PUMP TESTING WAS CONDUCTED AT BOREHOLES 14 & 16

Parameters recorded
- Time
- Volume pumped
- pH
- Conductivity
- TDS
- Iron Concentration
3 Paired t-Tests were conducted to compare each pH strip to the Hanna probe
- Conducted at $\alpha=0.05$
  - MN compared to Hanna probe
  - Extended Range compared to Hanna probe
  - Youth Waters compared to Hanna probe

Bland-Altman Difference Method conducted
- First Plot
  - Compares pH strip to Hanna probe
  - Line of equality
- Second Plot
  - (Probe-Test Strip) vs. Average of the two
  - Mean difference $\pm 2$ standard deviations
### PAIRED T-TEST RESULTS

<table>
<thead>
<tr>
<th>Variables</th>
<th>n</th>
<th>Mean Diff.</th>
<th>St.Dev.</th>
<th>St. Error</th>
<th>$t_{n-1}$</th>
<th>95% CI for Mean Diff.</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probe-MN</td>
<td>15</td>
<td>-0.026</td>
<td>0.26</td>
<td>0.066</td>
<td>2.145</td>
<td>(-0.17, 0.12)</td>
<td>0.71</td>
</tr>
<tr>
<td>Probe-ER(^a)</td>
<td>15</td>
<td>0.18</td>
<td>0.32</td>
<td>0.083</td>
<td>2.145</td>
<td>(-0.0024, 0.35)</td>
<td>0.053</td>
</tr>
<tr>
<td>Probe-YW(^b)</td>
<td>15</td>
<td>0.25</td>
<td>0.17</td>
<td>0.044</td>
<td>2.145</td>
<td>(0.16, 0.35)</td>
<td>0.00</td>
</tr>
</tbody>
</table>

- There was no significant difference in MN and Hanna probe pH measurements or in Extended Range and Hanna probe pH measurements.

- There was a significant difference in Youth Waters and Hanna probe pH measurements.
BLAND-ALTMAN
MN VS. HANNA PROBE

Mean difference = -0.026
SD = 0.26
BLAND-ALTMAN
EXTENDED RANGE VS. HANNA PROBE

Mean difference = 0.18
SD = 0.32
THERE IS A NEGATIVE LINEAR RELATIONSHIP BETWEEN PH & # OF JERRY CANS PUMPED

pH of water that has been in the borehole for some time is higher than in the aquifer.
A RELATIONSHIP BETWEEN IRON CONC. AND # OF JERRY CANS PUMPED CAN BE DEDUCTED

- Suggests iron levels in boreholes tested were at least partially due to corrosion
INITIAL IRON CONCENTRATION GEOGRAPHICALLY
<table>
<thead>
<tr>
<th>Borehole No.</th>
<th>No. of Pumps</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>--</td>
</tr>
<tr>
<td>2</td>
<td>--</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
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<tr>
<td>4</td>
<td>--</td>
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<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
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<td>8</td>
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<td>9</td>
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<tr>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>64</td>
</tr>
<tr>
<td>12</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>--</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
</tr>
</tbody>
</table>

Average: 11  
Standard Dev: 18  
% Passed: 9/12 = 75%
- Iron concentration stabilized at 1 mg/L
- pH stabilized around 6.15
- [Fe]: Test 1 - ended at 2.33 mg/L; Test 2 - 2 mg/L
- pH stabilized at 6.2
- Iron concentrations decrease with volume pumped
  - Corrosion of pump components contribute the bulk of the iron observed in borehole water.

- pH decreases with volume pumped
The cathodic reduction in the scale maintains the anodic oxidation of the iron metal.

Overall Reaction: \[ \text{Fe}(s) + 2\text{FeO}_2\text{H}(s) + 2\text{H}^+ \rightleftharpoons 3\text{Fe}^{2+} + 4\text{OH}^- \]
CONCLUSIONS & RECOMMENDATIONS
Results from Pump Tests at boreholes 14 and 16 suggest that much of the iron observed in borehole water produced by handpumps is from corrosion.

The MN and Extended Range test strips are statistically acceptable options for measuring pH in boreholes in Northern Uganda.

Iron concentration and pH of groundwater should be considered when determining how a borehole should be rehabilitated.
RECOMMENDATIONS TO FIELD WORKERS

The following should be noted:

- There is a correlation between aggressive groundwater and GI pipe and U2 pump corrosion.
- Boreholes will continue to be abandoned unless methods are implemented to reduce iron concentration levels.
- pH is a good indicator of groundwater aggressiveness and the potential for corrosion.
- pH test strips are a low-cost method for reliably measuring pH.
- pH of the groundwater should be measured before deciding on handpump type and materials to use in the borehole.
- Pump performance test results and pH measurements should be used to determine the source of iron and the type of rehabilitation needed for existing wells.
Repeat the pH strip study using pH test strips available in Northern Uganda.

Measure dissolved oxygen during pump testing to further investigate the Kuch Mechanism.

Measure ammonium concentration to determine if IRB are contributing to iron concentrations in the borehole.

Measure additional indices shown to predict corrosion: alkalinity, hardness, temperature, TDS, electroconductivity, calcium, chloride, and sulfate concentrations.

Further investigate the composition of the GI pipes available in the Gulu area.
THANK YOU!

Dr. Lackey
Dr. Butler
Dr. MacCarthy
Jake Carpenter
Candace Girod
Professor Harshbarger
REFERENCES